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EFFECT OF CAST STEEL PRODUCTION METALLURGY ON THE EMERGENCE OF CASTING DEFECTS

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The paper documents metallurgical possibilities of high alloy cast steel production in open induction medium frequency furnaces and an electric arc furnace in a gravity die casting foundry. The observation was focused on the emergence of gas defects in steel castings. The content of gases achieved during the metallurgical processes was evaluated for every unit of the production equipment and the casting ladle before casting into disposable sand moulds. The sand mould area was considered to be constant. The aim was to evaluate the current metallurgical possibilities of affecting the content of gases in high alloy cast steel in the current technical conditions of the foundry.

Keywords: metallurgy, high alloy steel, induction medium frequency furnace, electric arc furnace, defects

INTRODUCTION

Production plants of cast steel foundries are mostly equipped with a melting shop with an electric arc furnace (EAF) and an electric induction medium frequency furnace (EIMFF). The research was focused on metallurgical production possibilities of high-alloy cast steel of the P 91 type with modified chemical composition which is shown in Table 1, in standard foundry conditions without modern steel foundries units for out-of furnace treatment of steel primarily aimed at hydrogen and nitrogen contents in the melt. The production technologies of cast steel EAF and EIMFF are quite different, they are given by possible courses of individual production stages. The sum of the indicators of the contribution of input raw materials and the levels of metallurgical and technological processes gives then the resulting gas content in the melt. In high-alloy cast steel with imposed nitrogen content the melt may then bring the above critical content of gases which may initiate in the mould the defects of the cavity category, the gas holes in particular. These defects are characterized as cavities in the casting connected with its surface or as closed ones [1-3]. The gas holes show considerably diverse shapes. According to their origin they are classed as endogenous and exogenous ones. From the point of view of the melt metallurgy they are the endogenous gas holes that arise from the gases dissolved in the alloy. The endogenous gas holes are usually of lustrous non-oxidized surface, if not open after thermal treatment and following blasting of the casting surface.

Table 1 **Chemical composition of P91 steel / wt. %**

Composition	P91 X10CrMoVNb9-1; (1.4903)
C	0,06 - 0,12
Si	max. 0,50
Mn	0,30 - 0,60
P	max. 0,020
S	max, 0,015
Cr	8,00 - 9,50
Ni	max. 0,40
Mo	0,85 - 1,05
Nb	0,06 - 0,10
V	0,18 - 0,25
N	0,030 - 0,070
Al	max. 0,040

Chemical composition of the alloyed alloy is given by the standard with more detailed requirement by the customer. It follows from the operational experience that in deeply deoxidized steels it is very difficult to achieve especially low levels of hydrogen contents with furnaces working in the open atmosphere. This is due to the fact that the water vapour present in the atmosphere is decomposed on the metal bath surface to hydrogen and oxygen that are dissolved in the steel. In this case the [4] is applied as follows

$$H_2O = 2(H) + (O) \tag{1}$$

$$K_{H_2O} = \frac{a_H^2 \cdot a_O}{p_{H_2O}} \tag{2}$$

a_H^2 – hydrogen activity,
a_O – oxygen activity,
p_{H_2O} – partial pressure of water vapour.

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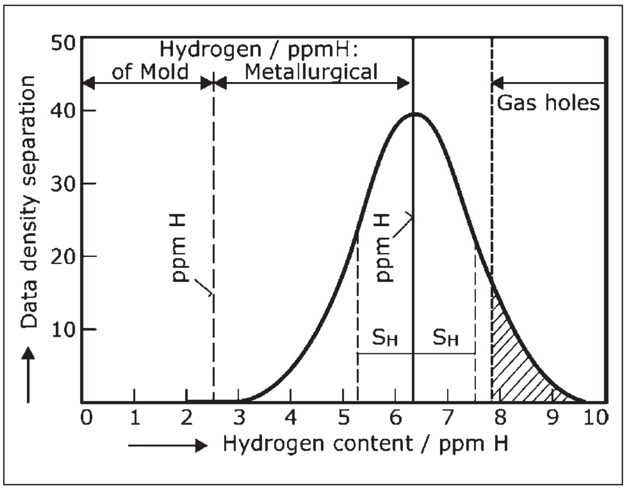

Figure 1 Representation of the sum of metallurgical hydrogen and hydro-gen from the mould and the impact on the probability of the occurrence of gas holes in the casting [4]

In the multicomponent systems, especially high-alloy steels, the solubility of hydrogen is also influenced by other components forces and, therefore, it is necessary to replace the concentrations with the activity. Then it follows from the equation (2) that significantly lower hydrogen contents can be achieved with these production conditions only after the optimal deoxidation in a foundry ladle.

It can be assumed that for high-alloy cast steel of the P 91 type, in compliance with the detailed technological rules, the oxygen content in the melt should not be the cause of the gas holes occurrence in the casting, and likely also the nitrogen, but especially the hydrogen content.

The area of the sand mould was assessed as a constant one provided the standard benefits of hydrogen. For example, in the case of steel with carbon content of 0,1 – 0,3 wt. % the Figure 1 shows the sum of hydrogen from the mould and metallurgical hydrogen and an impact on the probability of the occurrence of gas holes in the casting [4].

EXPERIMENTAL METHOD OF PRODUCTION OF THE P 91 STEEL

a) Manufacture of cast steel in the EAF

In order to achieve lower hydrogen contents in the melt from the EAF the production technology in the preparation of the charge and in individual metallurgical processes has been modified.

The charge was made up of chosen unalloyed metal scrap which was mechanically stripped of surface impurities and the share of the return waste was reduced. It has been found by testing that the hydrogen contents in mould risers reached the values up to 10 ppm of hydrogen. A part of the next charge was a carburizing agent in the volume which would guarantee the graphite melting min. 0,5 wt. % above the final melting analysis. The next additives were iron ore, lime and alloying ferro-additives containing elements with deep negative

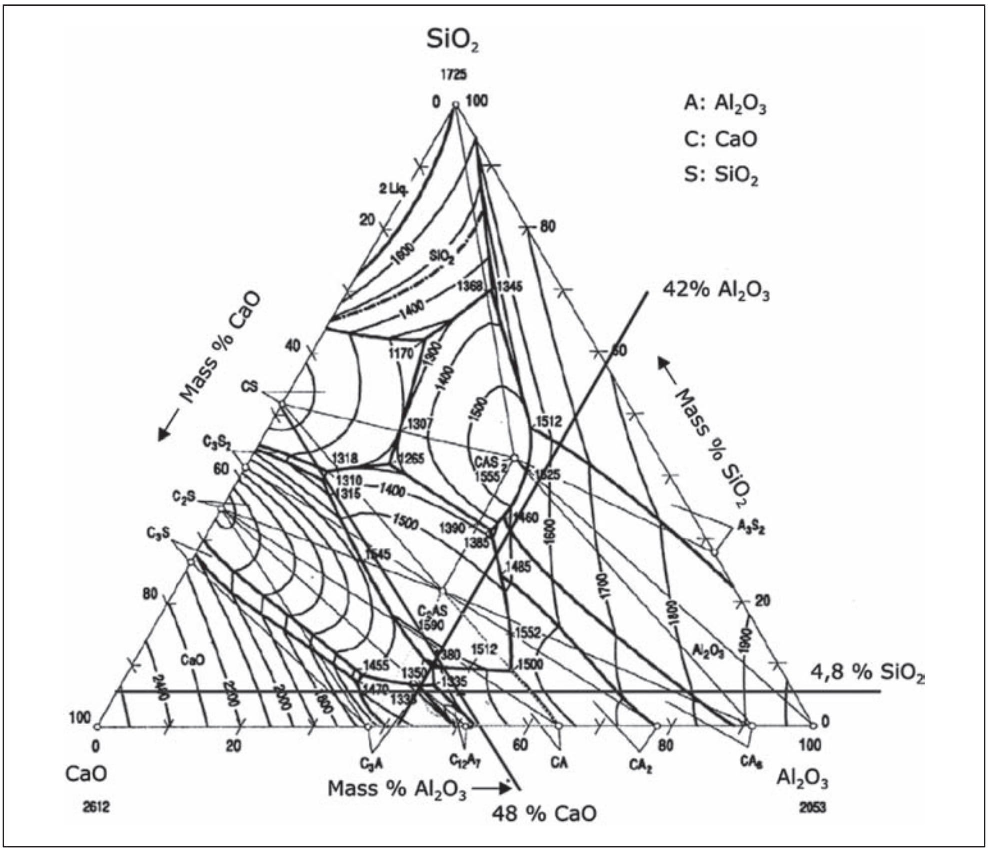

Figure 2 Area of chemical composition of the tested synthetic slag REFRAFLUX 4842 in the ternary chart Al_2O_3–CaO–SiO_2 [5, 6]

value of interaction coefficients to oxygen. The melting phase took place in the EAF by heat transfer into the bath by burning by an electric arc between three graphite electrodes and the charge without other intensification technologies. The oxidative phase started after melting the charge, taking the 1st test for chemical analysis and under the optimum temperature by adding on the bath surface a sufficient amount of the iron ore for inducing an intensive carbon boil. In the reduction phase a new slag was formed of a mixture of burned lime and synthetic slag Refraflux 4842, individual components were thrown in alternating dosage on the bath surface in the EAF. The basic chemical composition of tested synthetic slag in the form of the ternary diagram is given in Figure 2 [5, 6]. In such a way a liquid phase of the slag mixture was immediately formed which closed the melt surface and optimal conditions for desulphurization of steel were also subsequently created. After ending the desulphurization of the melt it was alloyed with low carbonaceous FeCr. The required nitrogen content was added in the form of ferro-additives. After ending the finishing the steel was tapped into the FL where additional precipitation deoxidation with alumi-nium including the application of SiCa in a full wire form and argon blowing through the porous block in the FL bottom took place. In such a way the temperature and chemical homogenization of steel was carried out in a short time interval.

After achieving the desired temperature the melt was cast into the sand mould.

Table 2 gives chemical hydrogen analyses of samples from the melt test which were taken in given individual production stages in the EAF and FL of P 91 steel.

The obtained results are also shown in Figure 3. Here are included the analyses of hydrogen in the EAF at the beginning of reduction (EAF at the start of reduction) that can be assessed as standardly good hydrogen contents including those ones in the melting conclusion (EAF before tapping). Hydrogen contents in the foundry ladle (FL after tapping) correspond to possibilities of the manufacturing technology. The final hydrogen content after ending the out-of furnace treatment of the melt before casting it in the mould (FL after SiCa) can be assessed as very good.

Achieving such values of hydrogen content then gives, provided the validity of the values in Figure 1 that have been verified many times, a high presumption that foundry defects of the hydrogen gas holes type will not be formed with a standard state of the sand mould. The casting surfaces after heat treatment and subsequent shot blasting are completely clean. An example of a clean casting without defects is shown in Figure 4.

Table 2 **Analyses of hydrogen in individual production stages in the EAF and FL of P 91 steel**

	Test Sample		
	No 1	No 2	No 3
	Hydrogen in the melt / ppm		
EAF start of the reduction	4,7	4,0	4,7
EAF before tapping	6,4	6,5	6,7
FL after tapping	7,0	7,3	7,0
FL after SiCa	5,5	5,7	5,7

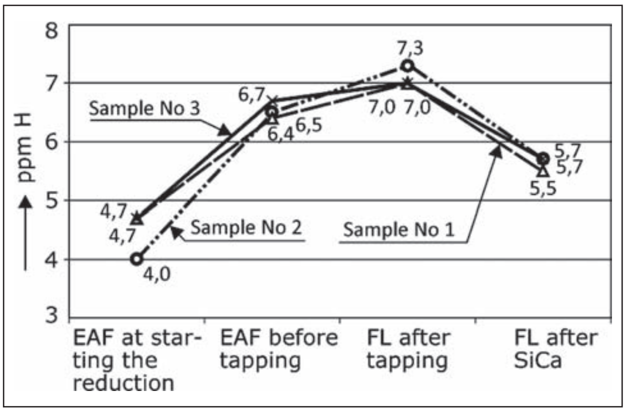

Figure 3 Analyses of hydrogen in individual production stages in the EAF and FL

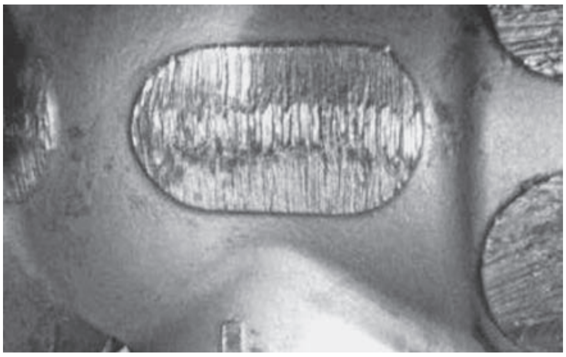

Figure 4 Representation of a clean casting without defects

b) Manufacture of cast steel in the EIMFF

In order to achieve lower hydrogen contents in the melt from the EIAF the production technology in the preparation of the charge and in individual metallurgical processes has been modified. The charge material was remelted high quality low carbonaceous alloyed material with a guaranteed hydrogen content of about 2,2 ppm. FeCr was annealed up to red heat, the required nitrogen content was added in a form of ferro-additives and other alloying additives according to the calculation up to the final analysis according to Table 1. After turning on the furnace the melting phase was finished by melting of the charge. In subsequent phase of finishing the slag was skimmed and a new one was formed from the tested sintered synthetic slag Refraflux [3]. Basic chemical composition of the sintered slag is in the form of a ternary diagram shown in Figure 2. This refining slag meltable under low temperatures with maximum skimming of the primary slag was completely liquid already at temperature of 1 330 °C – 1 350 °C and immediately it formed a liquid phase which completely closed the melt surface and the conditions for partial desul-

Table 3 **Analyses of hydrogen in individual production stages of the P 91 steel in the EIMFF and FL**

	Test sample No 1	Test sample No 2	Test sample No 3
	Hydrogen in the melt / ppm		Nitrogen in the melt / ppm
After melting (RZ)	3,0	3,0	295
In the foundry ladle (FL)	3,8	4,0	310
FL after CaSi	3,6	3,8	330

phurization of steel were subsequently also created. Under the required temperature the melt was fine alloyed and it was tapped in the FL. In the foundry ladle the steel was additionally deoxidized with Al including SiCa, argon was blown through the porous block in the FL bottom and the temperature and chemical homogenization of steel was carried out in a short time interval. After achieving the desired temperature the melt was cast into the sand mould.

Table 3 gives the chemical analyses of hydrogen samples from the melt test which were taken in given individual production stages of the P 91 steel in the EIMFF and FL.

The obtained results are also shown in Figure 5. Here are included the analyses of hydrogen and nitrogen in the EIMFF after finishing the melting phase (RZ), of hydrogen in the foundry ladle (FL) and the final hydrogen content after ending the out-of furnace treatment of the melt before casting it in the sand mould (FL after SiCa).

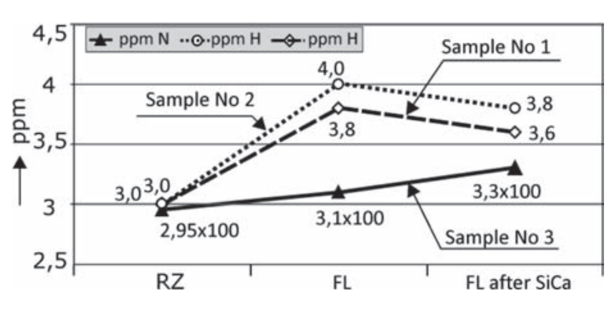

Figure 5 Analyses of hydrogen in individual production stages in the EIMFF and FL

The final hydrogen contents are in accordance with required chemical composition. Achieved hydrogen contents in the FL can be assessed as good ones and provided the validity of values in the Figure 1, which were operationally validated many times, they give a high assumption that foundry defects of the hydrogen gas holes type will not be formed.

CONCLUSIONS

Steel casting foundries using gravity casting method into sand moulds operate melting units the EAF and the EIMFF. They mostly, however, have not available the most modern equipment for secondary metallurgy. The research task was to examine whether, with the absence of this technological equipment, the production of high-alloy cast steel of the P 91 type can be solved with new modern ways of the production technology and special materials with focusing on the emergence of defects of a gas character.

Metallurgical and technological processes for the production of the melt for the P 91 steel with modified chemical composition were tested. Standard manufacturing processes brought the highest occurrence of casting defects of the gas character of the gas holes type. According to the analysis of the melt in the FL, the probable cause was the high hydrogen content in the melt. Crucially, these defects were uncovered after heat treatment and subsequent blasting the casting surface.

New and modern metallurgical and technological production processes in the manufacture of high-alloy cast steel of the P 91 type for sand moulds were tested in the EAF, EIMFF and FL and the development of hydrogen content in the melt was studied, provided the optimal deoxidation of the melt, oxygen activity and the achievement of the desired nitrogen content. It follows from the obtained results that the final hydrogen contents in the melt in the FL after final out-of furnace treatment in the melt from the EAF reached the average value of 5,6 ppm of hydrogen and in the melt from the EIMFF the average value of 3,7 ppm of hydrogen.

It has been proved that with the absence of a modern technological equipment for secondary metallurgy the manufacture of high-alloy cast steels of the 91 P type can be solved with new ways of the production technology using the furnace unit and in the FL with the use of modified charge materials and special slag-forming materials. Hydrogen contents obtained in the melt, provided the standard preparation of the sand mould, are safe and will not create foundry defects of the hydrogen gas holes type.

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