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INFLUENCE OF INITIAL CHARGE TEMPERATURE AND FURNACE EXPLOITATION ON STEEL LOSS

Steel loss related to the formation of scale is a parameter that is of great importance in the charge heating process. The value of steel loss determined by the thickness of the scale layer affects the intensity of the heat transfer process in the heating furnace, but also constitutes a significant element in the heat-material balance. Reducing the loss of steel during charge heating has a positive effect on heat consumption and material losses, which is extremely important in the context of energy and resource savings, the main elements of sustainable development processes.

The methodology of determining the loss of steel to scale in an industrial heating furnace is presented in the paper. The results of calculations for various charge temperatures at the entrance to the furnace are presented. The influence of furnace operating conditions on steel loss is discussed

Keywords: heating of steel charge, loss of steel, initial charge temperature, furnace exploitation

1. Introduction

During the heating of steel before plastic processing, heat exchange processes are accompanied by mass exchange processes between the furnace atmosphere and the surface of the heated steel. As a result of these interactions, changes in the chemical composition of the surface layers changes. These changes are mainly caused by oxidation, which causes a significant loss of steel. The formed scale, in addition to direct losses, also causes a number of indirect losses, including, among others, reduced durability of furnace equipment and lining, increased wear of equipment and tools on the rolling line, surface defects of semi-finished products, and reduced intensification of heat exchange in the furnace [1]. The problem of steel loss to scale also concerns the heating of the porous charge [2].

The loss of steel in the heating process is influenced by the heating parameters, which include the composition of the furnace atmosphere, initial and final charge temperature, furnace temperature, heating time, heating rate, furnace efficiency, and heating technology.

In addition to the mentioned parameters, the operation of heating furnaces plays an important role in the process of heating the steel charge. Optimal exploitation of the furnace can minimize heat consumption, steel loss for scale, and ensure high quality of final products and semi-finished products.

The correct operation of furnaces is determined by a number of factors, including [3,4]:

– the method of loading the furnace charge,
– use of the enthalpy of the charge entering the furnace,
– use of the enthalpy of exhaust gases from the furnace,
– the course of the combustion process,
– furnace gas dynamics,
– heat exchange in the furnace,
– the amount of scale formed during heating,
– adaptation of heating technology to production capabilities,
– optimal control and automation of the heating process.

The source of significant savings in the process of heating the steel charge can be the use of the enthalpy of the charge entering the furnace. The charge with increased temperature, even around 700°C, can be transferred directly from continuous casting machine. This allows us to achieve technological heating conditions in about 50% shorter time [5,6]. When calculating the economic effects of using heat from the hot charge, the primary factor is the fuel economy in heating furnaces, which translates directly into the specific heat consumption. Another study [7] proves that the use of the enthalpy of the hot charge in the heating process allows us to reduce the specific heat consumption by about 25%. As the steel loss for scale correlates with the heat consumption [8-10], it can be assumed that the charge temperature at the entrance to the furnace also has an impact on the steel loss.

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2. Research subject and methodology

The tests, involving heating the billets before plastic processing, were carried out in a walking beam furnace with a nominal capacity of 140 t/h. The walking beam furnace had five conventional heating zones and was fired with high-methane natural gas. The steel charge in the form of cold (20-60°C), warm (200-300°C), or hot (600-700°C) billets was heated in the furnace. The charge temperature after leaving the furnace was similar in all cases and, on average, amounted to 1050°C.

The temperature of the charge fed to and removed from the furnace was measured with a Flir P-64 thermal imaging camera. The temperature in individual zones of the furnace was measured sing a NiCr-NiAl thermocouple and the composition of the exhaust gases was measured using an MRU *plus* analyzer.

The amount of scale formed during heating of the ~~B500SP~~ charge was determined by the mass method, using specially prepared steel samples (Fig. 1).

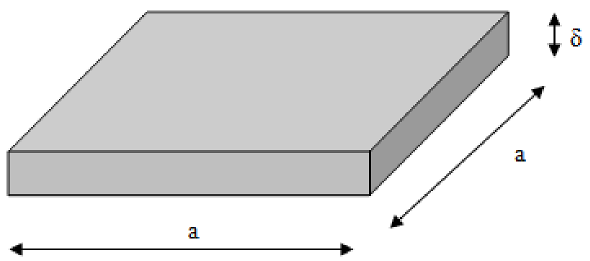

Fig. 1. Steel samples used for testing

The samples were prepared by cutting billet slices from the batch of charge to be heated. The research was conducted for the samples made from steel grade B500SP the following composition: C-0.12%, Mn-1.01%, Si-0.19%, P-0.018%, S-0.027%, Cr-0.10%, Ni-0.13%, Cu-0.25%, Al-0.003%, Mo-0.022%, Sn-0.013%, V-0.003%, Ti-0.001%, B-0.0003%, Zn-0.013%, N-0.0085%, Pb-0.001%. The samples were weighed (mass m_0) and then added to the charge and delivered to the furnace in specially prepared "baskets" dimensionally matched to the charge and samples (Fig. 2).

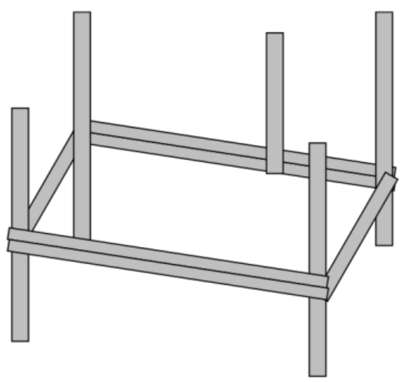

Fig. 2. Sample basket for testing

The amount of scale was determined as the difference between the mass of the sample after heating and the mass of the sample after cleaning, related to the total area of the sample:

$$z' = \frac{m_1 - m_2}{1000 \cdot A} \tag{1}$$

where:

m_1 – sample weight after heating, g,
m_2 – sample weight after complete descaling, g,
z' – the amount of scale, kg/m^2,
A – sample area, m^2,

$$A = 2 \cdot a^2 + 4 \cdot a \cdot \delta \tag{2}$$

where:

a – side dimension of the sample, m ($a = 0.16$ m),
δ – sample thickness, m ($\delta = 0.02$ m).

The steel loss for scale was calculated according to the formula:

$$z = \frac{m_0 - m_2}{1000 \cdot A} \tag{3}$$

where:

m_0 – sample weight before heating, g,
z – steel loss for scale, kg/m^2.

3. Results of measurements and calculations

6 samples were heated for the following variable charge temperature parameters and furnace operating conditions:

1 – hot charge, average excess combustion air ratio $\alpha = 1.44$, standard technology, sample heating time $\tau = 4$ h 25 min (including maintenance shutdowns $\tau = 2$ h 25 min rolling mill failure);
2 – hot charge, average excess combustion air ratio $\alpha = 1.21$, standard technology, sample heating time $\tau = 2$ h 6 min (including maintenance shutdowns $\tau = 0$);
3 – hot charge, average excess combustion air ratio $\alpha = 1.11$, standard technology, sample heating time $\tau = 2$ h 8 min (including maintenance shutdowns $\tau = 10$ min);
4 – cold charge, average excess combustion air ratio $\alpha = 1.08$, standard technology, sample heating time $\tau = 2$ h 18 min (including maintenance shutdowns $\tau = 10$ min);
5 – hot charge, average excess combustion air ratio $\alpha = 1.15$, standard technology, sample heating time $\tau = 2$ h 30 min (including maintenance shutdowns $\tau = 20$ min);
6 – hot charge, average excess combustion air ratio $\alpha = 1.04$, changed technology, sample heating time $\tau = 2$ h 15 min (including maintenance shutdowns $\tau = 10$ min);

The temperatures in the various zones of the furnace during charge heating are shown in Fig. 3.

The measurement results are summarized in Table 1.

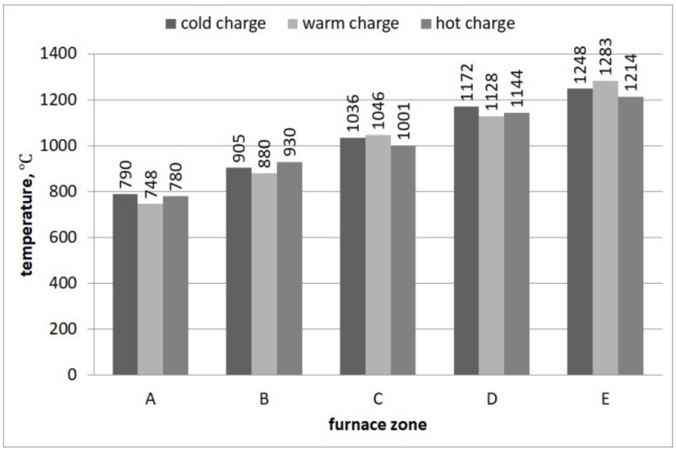

Fig. 3. Comparison of temperature indications in the furnace chamber area during batch heating: A – regeneration zone, B – I preheating zone, C – II preheating zone, D – heating zone, E – equalizing zone

TABLE 1

Results of adhesion measurements

Sample No.	m_0, g	m_1, g	m_2, g	z', kg/m^2	z, kg/m^2
1	3941	3971	3691	4.375	3.906
2	4008	4035	3820	3.359	2.938
3	4085	4130	3945	2.891	2.188
4	3942	3987	3801	2.906	2.203
5	3963	4002	3804	3.094	2.484
6	4002	4034	3882	2.375	1.875

4. Conclusions

Based on the measurements and calculations carried out, it can be concluded that the initial temperature of the charge and the operating conditions of the furnace affect the steel loss for scale. When considering a properly conducted heating process (in the case of a hot charge, sample 6), it can be seen that the amount of scale and the loss of steel decrease with the increase of temperature of the charge entering the furnace

In the case of heating the hot charge, 4 cases were analyzed, on the basis of which the conclusion can be drawn that each longer stoppage (maintenance shutdown or breakdown) causes a significant increase in steel loss due to the prolonged charge residence time in the oxidation zone. In addition, when comparing the results for samples 5 and 6, attention should be paid to the proportions between the air stream and the combustion gas stream for the individual zones of the furnace. During the heating of the hot charge, it is not recommended to cut off the gas supply to the burners in the I preheating zone to only allow air to pass through (sample 5) because it affects the amount of scale formed. The heat flux should be reduced proportionally in all zones by limiting the gas flow with the appropriate air flow and heating the I preheating zone (sample 6).

The oxygen content in the exhaust gas has a strong influence on the amount of scale formed during the heating of the billets. Despite the longer heating time for sample 5, a smaller amount of scale was produced than for sample 2, because lower values of oxygen concentration (lower excess combustion air ratio) were observed in the flue gas.

In addition, the performed measurements and calculations confirm the thesis about the correlation between steel loss for scale and heat consumption.

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