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EFFECT OF HEATING TECHNOLOGY ON SCALE ADHESION IN THE STEEL CHARGE HEATING PROCESS

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The adhesion of scale to the steel substrate is an important parameter in the charge heating process before plastic processing. A low value of adhesion adversely affects the operation of heating furnaces, while too high value causes the scale to roll into a steel product and deteriorate its purity and quality. The paper presents the methodology of adhesion determination and the results obtained on the basis of the presented methodology. The influence of heating technology on adhesion for constant furnace efficiency and different values of excess air ratio is discussed. The furnace efficiency and the excess air ratio are the basic parameters of the process. It is extremely important in the context of the challenges of optimizing production processes, which in turn is an important element of the circular economy.

Keywords: steel, electric furnace, heating of steel charge, oxidation, scale adhesion

INTRODUCTION

One of the integral elements of the operation of heating devices related to the heating process is the phenomenon of adhesion of the scale layer to the steel substrate. Adhesion, i.e. the strength of the bond between the scale and the substrate, is the result of many factors [1-3].

Theoretical studies and laboratory tests [4-6] addressed the problem of the influence of heating time and temperature, furnace atmosphere and chemical composition and structure of steel on the adhesion of the scale. In terms of constant capacities or heating technology, the composition of the furnace atmosphere depends primarily on the excess combustion air ratio.

Based on the results of [1, 7], it can be assumed that the furnace operating conditions are determined by the heating technology and the capacity of the furnace for a given technology. Based on the results of the calculations, it can be concluded that the increase in the intensity of the heating process, determined by the rate of surface temperature increase, results in a significant increase in the capacity of furnaces [6]. For a thicker charge, an increase in the heating intensity increases the capacity, but only up to a certain heating rate. A further increase has little effect on the capacity of the furnace and becomes irrational for thermal reasons and, in extreme cases, impossible [1, 7].

The calculation results clearly indicate that in order to obtain the maximum capacity, the technologies used in real furnaces should be similar to the theoretical ones. The oxidation process (steel loss for scale) also depends on the capacity of the furnace, which is confirmed by the results of [7].

The dependence of steel loss on capacity is described in more detail in [6, 8]. On this basis, it can be concluded that the capacity affects the loss of steel; taking into account, a correlation between the steel loss and the adhesion of the scale in terms of the furnace capacity can be observed.

The heating curves for traditional technology T(a) and for energy-saving technology T(b) are shown in Figure 1. Curve verification is described in [8].

The aim of the research was to determine the adhesion for various technologies ensuring constant capacity

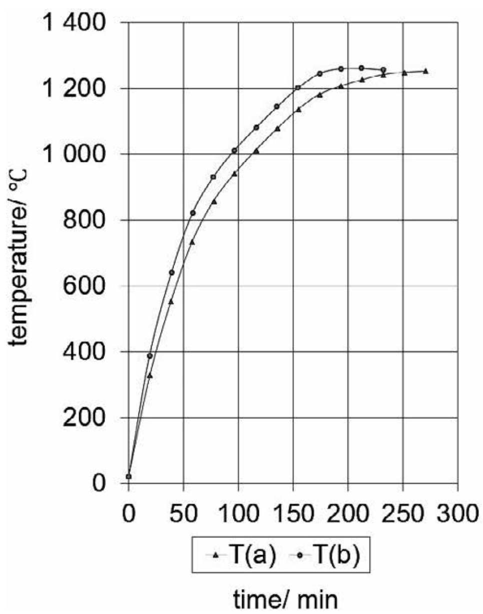

Figure 1 Heating curves

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of the furnace. Variable values of the excess combustion air ratio for traditional technology T(a) and energy-saving T(b) for the furnace capacity w = 60 t/h were analyzed.

MEASURING STAND AND SCOPE OF RESEARCH

Heating was conducted in an electric tube furnace (with a combustion chamber) equipped with a SHIMADEN-FP93 programmable controller [8].

The samples were heated in the flue gas atmosphere at excess combustion air levels of α = 0,8; 1,0 and 1,2 to the charge surface temperature t = 1 250 °C. The samples were made of steel. A detailed description of the measuring station and the dependencies allowing for the calculation of scale adhesion are presented in [5, 8].

The next steps in the measurement of adhesion are shown in Figure 2.

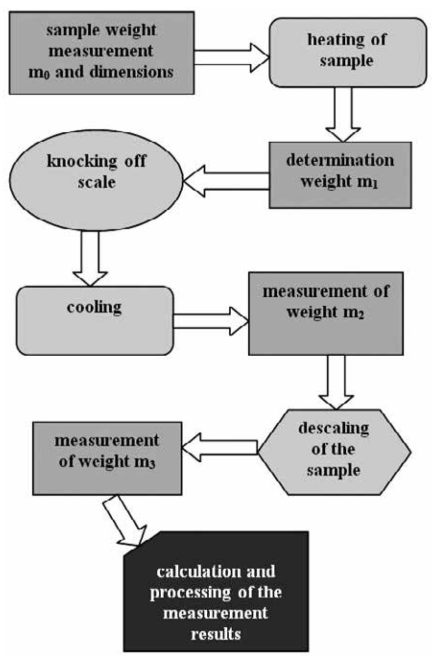

Figure 2 The next steps in the measurement of adhesion

The adhesion of the scale layer is determined by the ratio of the weight of the scale which remains after knocking off, to the total weight of the scale [5]:

$$P = \frac{m_2 - m_3}{m_1 - m_3} \cdot 100\% \qquad (1)$$

where:

m_1 – sample mass after heating/ g,
m_2 – sample mass after knocking off scale/ g,
m_3 – sample mass after complete cleaning/ g,
P – scale adhesion defined by the percentage fraction of scale left on the steel core after hitting by the ram/ %.

The m_2 and m_3 masses are determined by weighing the samples on a laboratory scale. Determining mass m_1 in the same way is impossible, due to the high temperature of the sample. It can be determined from the following equation:

$$m_1 = m_0 + \frac{1000 \cdot z \cdot A}{x_{Fe}} \qquad (2)$$

where:

m_0 – sample mass before heating/ g,
z – loss of steel due to scale/ kg/m^2,
A – sample surface area/ m^2,
x_{Fe} – elementary iron mass fraction of the scale.

The steel loss in the process of charge heating was determined based on experimental research from the following equation (3):

Table 1 **Measurement results**

Value of excess air α, -	Initial mass of sample m_0/ g	Sample weight after knocking off m_2/ g	Sample weight after cleaning m_3/ g	Size of sample side a/ mm	Sample height h/ mm
Technology T (a)					
0,8	317,092	308,941	285,108	29,90	49,85
1,0	321,115	304,525	274,539	30,25	50,65
1,2	316,697	288,873	258,341	29,75	49,65
Technology T (b)					
0,8	316,451	307,264	286,346	29,75	49,95
1,0	319,233	299,222	276,883	30,05	50,15
1,2	315,991	284,570	263,550	29,25	49,85

Table 2 **Calculation results**

Value of excess air α, -	Sample surface A/ m^2	Steel loss z/ kg/m^2	Sample weight after heating m_1/ g
Technology T (a)			
0,8	0,007750	4,127	360,314
1,0	0,007959	5,852	384,056
1,2	0,007678	7,600	395,556
Technology T (b)			
0,8	0,007714	3,903	357,133
1,0	0,007834	5,406	376,463
1,2	0,007544	6,952	386,863

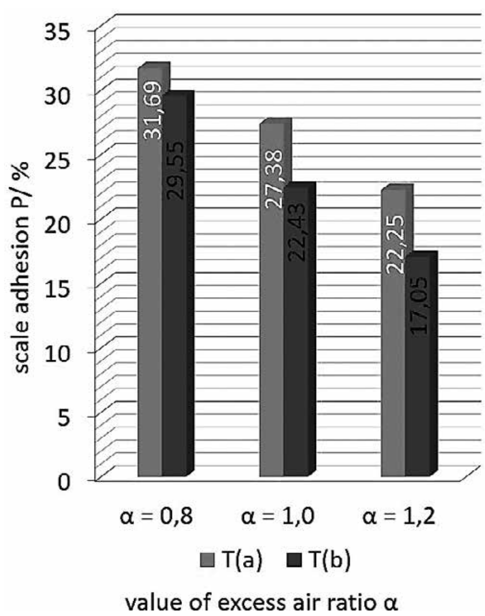

Figure 3 Results of scale adhesion measurement

$$z = \frac{m_0 - m_3}{1000 \cdot A} \quad (3)$$

MEASUREMENT AND CALCULATION RESULTS

Measurements and calculations of the sample masses and steel losses due to scale were carried out in subsequent stages of research. The results are summarized in Table 1 and Table 2. The scale adhesion calculation results are presented in Figure 3.

SUMMARY

Based on the research carried out, the following conclusions can be made:

- The heating technology has a significant impact on the loss of steel and the adhesion of scale to the steel substrate.
- An increase in the excess combustion air ratio increases the steel loss for scale.
- The adhesion of the scale to the steel substrate decreases with increasing value of the excess combustion air ratio.
- There is a correlation between steel loss and scale adhesion.
- An increase in steel loss, within a given heating technology, reduces the adhesion of the scale to the steel substrate.
- The use of energy-saving technologies allows reducing the loss of steel and the adhesion of scale to the steel substrate. This can be explained by the shorter residence time of the charge in the high temperature zone (above 1 000 °C).

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Note: The responsible translator for English language is dogadamycie.pl Sp. z o. o., Koszalin, Poland