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EFFECT OF FURNACE EFFICIENCY ON SCALE ADHESION IN THE STEEL CHARGE HEATING PROCESS

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The paper presents the results of research on the influence of the efficiency of a metallurgical heating furnace on the adhesion of scale formed during the heating process of the steel charge. The methodology for measuring the adhesion of scale to the steel substrate as well as the measurement stand by means of which the research plan was carried out were presented. In addition, the method for determining the heating curves for selected furnace performance and measurement results are presented. The calculation results demonstrating the effect of efficiency on scale adhesion are summarized.

Key words: furnace efficiency, heating of steel charge, heating temperature, scale adhesion, oxidation

INTRODUCTION

An important issue in the process of heating steel charge in heating furnaces is the adhesion of scale to the steel surface. Too poor adhesion of the scale may cause damage to the refractory lining of the furnace hearth, which is also associated with the need to stop the furnace operation. On the other hand, too strong adhesion may lead to the fact that unremoved scale remains will be rolled into the surface of the products during the plastic forming process, which may negatively affect the final quality of the products [1]. It should be noted that it is necessary to carry out research that will allow technology that ensures optimal scale adhesion to be developed.

The operation of heating devices is strictly related to the phenomenon of adhesion of the scale layer to the steel substrate. Adhesion, or the strength of scale binding to the substrate, is the resultant of many factors. It depends, among others on the time and temperature of heating, the composition of the gas atmosphere as well as the chemical composition and structure of the steel [1-4]. Previous theoretical studies and laboratory tests [2, 3] discussed the problem of the influence of the time and temperature of heating and the atmosphere of the furnace on scale adhesion . The influence of the surface state of the charge on scale formation and adhesion is addressed in [5-7].

The adhesion of scale to the steel core is to a significant extent determined by two phenomena: mechanical adhesion and specific adhesion. The first one is the result of unevenness on the core surface, which promotes the adhesion of scale to the substrate. The second factor - specific adhesion occurs only in conditions of close adherence of both phases to each other, because it is related to the interaction of intermolecular forces. Cohesive forces decrease during the reaction, which is the result of processes taking place on the core surface. The reduction of adhesion forces caused by the precipitation of empty nodes at the interface between the scale and metal leads to the formation of micro and macropores. The adhesion of scale to the metallic substrate is determined by the area in which the liquidation of empty nodes occurs [3]. It is worth noting that one of the most important factors affecting the heating process and the performance of heating furnaces is the efficiency of the furnace. The paper presents the results of research on the adhesion of scale to the steel substrate for various efficiencies.

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SCOPE OF RESEARCH

The aim of the research was to determine the adhesion of scale to the steel substrate for different values of excess air necessary for combustion at a given furnace efficiency. The final result of the work was the analysis of the influence of excess air on adhesion. The research was carried out on samples with a square cross-section of 30 x 30 mm and a height of 50 mm. The samples were made of steel.

The prepared samples were heated in the atmosphere of exhaust to the charge surface temperature t = 1 250 °C; for the value of excess combustion air α = 0,8; 1,0; 1,2. Three furnace efficiencies w = 40, 60 and 80 t/h executed for a specific heating technology were analyzed. Attempts to heat the samples were carried out for the assumed process parameters and furnace efficiency. Measurements and calculations of steel loss and the adhesion of scale to the steel substrate were made.

MEASURING STAND

Heating was carried out in an electric tubular furnace (with a combustion chamber) equipped with a programmable controller SHIMADEN-FP93 [8]. Starting the measurement stand required pre-programming of the heating curve using a programmable controller. After starting the program, the furnace, by means of the programmable controller FP93, automatically performed heating in the steps defined by temperature and time. The furnace was controlled by the temperature of the heating chamber measured by a PtRh-Pt thermocouple. The gas burner was used to produce a specific exhaust environment in the heating chamber of the furnace. Combustion took place at specific volume streams of the substrates. The air and gas flow rates were controlled by means of rotameters. A descaling device was used to determine the adhesion of the scale, the principle of which was described in the works [2].

HEATING CURVES

The basis for conducting laboratory tests were heating curves developed on the basis of temperature measurements in successive zones of a real pusher furnace located in the rolling mill of one Polish steelworks. The temperature values and heating times were entered into the internal memory of the FP93 programmable controller.

The heating curves are shown in Figure 1. For the determined heating curves, the surface temperature of the sample and the temperature of the heating chamber were measured. Tables 1 - 3 present the results of surface temperature measurements, temperature settings and the results of deviation calculations from the heating curves for the three furnace efficiency values.

Analyzing the tables above, it can be concluded that up to about 800 °C there are significant temperature differences between the set point and the temperature of the heating chamber. The greater the differences are, the greater the efficiency is. The average deviation from the set point for the entire heating period amounts to ± 7,5 °C for w = 40 t/h, ± 10,4 °C for w = 60 t/h, ± 23,5 °C for w = 80 t/h. Such a state is caused by the influence of energy supplied from the gas burner, the power of which does not change at steady gas and combustion air flows. After reaching a temperature of over 800 °C, this temperature is stabilized. The average deviation from the set point for this heating period is around ± 2 °C for w = 40 t/h and w = 60 t/h, and ± 7.5 °C for w = 80 t/h.

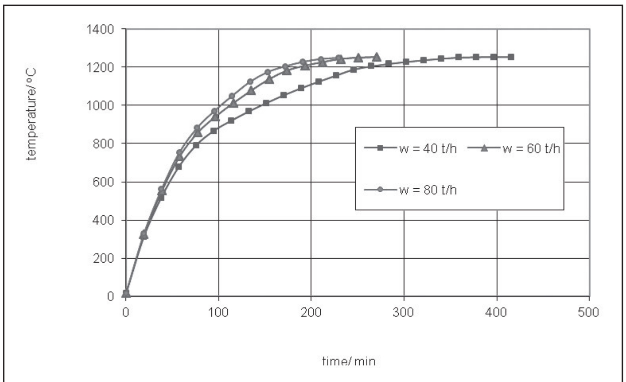

Figure 1 Heating curves

Table 1 **Results of temperature measurements and deviation calculations from heating curve for w = 40 t/h**

Time/ τ min	Set temperature/°C	Chamber temperature/ °C	Deviation /°C	Sample temperature/°C
0,0	20	20	0	20
18,9	371	487	- 116	352
37,8	602	664	- 62	563
56,6	767	812	- 45	691
75,5	869	898	- 29	843
94,4	934	952	- 18	917
113,3	989	991	- 2	954
132,2	1 037	1 029	8	1 012
151,0	1 080	1 073	7	1 046
169,9	1 118	1 107	11	1 087
188,8	1 153	1 138	15	1 112
207,7	1 186	1 177	9	1 148
226,5	1 217	1 220	- 3	1 187
245,4	1 247	1 238	9	1 207
264,3	1 267	1 259	8	1 219
283,2	1 272	1 263	9	1 235
302,1	1 271	1 270	1	1 239
320,9	1 267	1 265	2	1 242
339,8	1 261	1 258	3	1 244
358,7	1 257	1 253	4	1 247
377,6	1 256	1 254	2	1 244
396,5	1 256	1 253	3	1 248
415,3	1 255	1 252	3	1 247
434,2	1 255	1 254	1	1 251

Table 2 **Results of temperature measurements and deviation calculations from heating curve for w = 60 t/h**

Time/ τ min	Set temperature/°C	Chamber temperature/°C	Deviation /°C	Sample temperature/°C
0,0	20	20	0	20
19,3	387	495	- 108	349
38,6	640	678	- 38	581
57,9	820	854	- 34	788
77,3	930	951	- 21	893
96,5	1 011	999	12	957
115,8	1 081	1 069	12	1 015
135,1	1 144	1 136	8	1 097
154,4	1 201	1 205	- 4	1 146
173,7	1 246	1 247	- 1	1 197
193,0	1 260	1 254	6	1 204
212,3	1 261	1 259	2	1 211
231,6	1 256	1 256	0	1 218
250,9	1255	1258	- 3	1226
270,2	1255	1255	0	1239
289,0	1255	1253	2	1248

Table 3 **Results of temperature measurements and deviation calculations from heating curve for w = 80 t/h**

Time/ τ min	Set temperature/°C	Chamber temperature/°C	Deviation/ °C	Sample temperature/°C
0,0	20	19	1	18
19,7	405	527	-122	329
39,5	681	775	- 94	631
59,2	874	893	- 19	818
78,9	996	1 008	- 12	943
98,7	1 092	1 087	5	1 014
118,4	1 180	1 195	- 15	1 127
138,2	1 235	1 239	- 4	1 192
157,9	1 247	1 253	- 6	1 206
177,6	1 248	1 261	- 13	1 229
197,4	1 251	1 255	- 4	1 237
217,1	1 253	1 252	1	1 245

The surface temperature deviations from the set point and chamber temperature to 800 °C have no significant effect on the adhesion of scale to the steel substrate because in this temperature range, in principle, a negligible amount of scale is formed. Scale adhesion at temperatures below 1 000 °C does not exceed 5 %, which is confirmed by the studies presented in [3].

The adopted settings of the furnace temperature can be considered as correct.

METHODOLOGY OF SCALE ADHESION MEASUREMENTS

In order to analyze the effect of furnace efficiency on the adhesion of scale in the heating process of the steel charge, the methodology for determining the adhesion of scale to steel was developed. The mass method was used for this purpose. It consists in directly determining the mass of samples in subsequent stages of research [2, 3].

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 [2]:

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

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:

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

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 4 and Table 5. Analyzing Table 5 can be stated that with the increase in efficiency, the loss of steel due to scale decreases, whereas it increases with an increase in the value of excess air. The scale adhesion calculation results are presented in Figure 2. Analyzing Figure 2, it can be noticed that the adhesion of scale to the steel substrate decreases with increasing efficiency. The lowest value was obtained for w = 80 t/h. This is probably due to the fact that the residence time of the charge at temperatures decisive for adhesion (above 1 000 °C) decreases with increasing efficiency. Moreover, an increase in the excess air value decreases scale adhesion.

Table 4 **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
efficiency w = 40 t/h					
0,8	313,060	309,330	265,860	29,80	49,50
1,0	312,530	303,490	255,735	28,75	48,75
1,2	313,543	297,556	245,523	28,15	49,25
efficiency w = 60 t/h					
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
efficiency w = 80 t/h					
0,8	311,354	304,512	293,598	29,85	49,65
1,0	312,585	296,145	281,452	30,25	50,65
1,2	314,434	287,487	275,574	28,5	50,15

Table 5 **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
efficiency w = 40 t/h			
0,8	0,00767	6,149	376,84
1,0	0,00725	7,824	389,28
1,2	0,00713	9,539	405,46
efficiency w = 60 t/h			
0,8	0,00775	4,127	360,31
1,0	0,00795	5,852	384,05
1,2	0,00767	7,600	395,55
efficiency w = 80 t/h			
0,8	0,00771	2,303	335,34
1,0	0,00795	3,912	354,65
1,2	0,00734	5,293	366,94

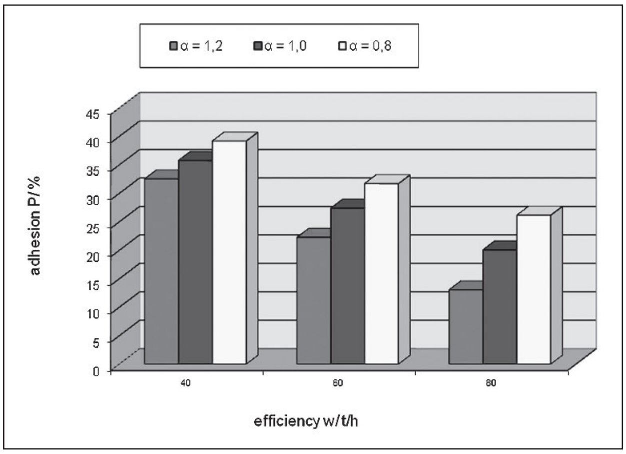

Figure 2 Scale adhesion calculation results

SUMMARY

On the basis of the conducted research, the following conclusions can be specified:

- Furnace performance has a major impact on steel loss and the adhesion of scale to the steel substrate.
- Steel loss decreases with increasing efficiency.
- Scale adhesion decreases with increasing productivity as well.
- The lowest value of adhesion is obtained for the highest efficiency, which is probably due to the fact that the residence time of the charge at temperatures decisive for adhesion (above 1000°C) decreases with increasing efficiency.
- An increase in the value of excess air causes an increase in the loss of steel due to scale, but the adhesion of scale to the steel substrate decreases.
- There is, of course, a correlation between the loss of steel and scale adhesion .
- With an increase in steel loss, for a constant value of excess air, the adhesion of scale to the steel substrate increases.
- Extending the research on the influence of efficiency on scale adhesion and taking into account the results of the research on the influence of other heating parameters may result in the development of technologies that will ensure optimum scale adhesion.

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Note: The responsible translator for English language is Christine Frank-Szarecka, Częstochowa, Poland