Research Article

THE VERIFICATION OF THE INFLUENCE OF HEATING STEEL CHARGE PARAMETERS ON THE THICKNESS OF SCALE LAYER

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ABSTRACT

Parameters of heating are understood as the conditions in which heating process is conducted to obtain the required steel properties. During the heating process, on the surface of heated elements, layer of scale is formed as a by-product,. The selection of appropriate heating parameters allows for achieving the required layer of scale, and thus the predictability of the process effects . The article presents sample calculations of heating parameters for the charge of steel and the analysis of the results of conducted experiments.

Key words: heating of steel, oxidation, scale.

List of designations
A – the surface area, m^2,
t – temperature, ℃,
m_0 – mass of the specimen before heating, kg,
m_3 – mass of the specimen after complete cleaning, kg,
α – value of combustion air excess ratio,
x_{Fe} – part of iron in the scale (0.74),
s – thickness of scale layer, m,
z – surface steel loss for scale, kg/m^2,
τ – heating time, h,
ρ – density of scale, (3900 kg/m^3),

INTRODUCTION

In the process of heating steel before plastic working, in addition to heat exchange-related processes, the processes of chemical interaction also occur between the furnace atmosphere and the surface of the steel being heated. As a result of oxidation, scale forms, which causes not only the losses of the heated material,slows down the heating process and increases the consumption of fuel, but also adversely affects the service file of heating equipment [1–3]. The most important external factors influencing the formation of scale are:
- heating time,
- temperature of steel charge,
- temperature of furnace chamber,
- furnace atmosphere [4, 5].

The selection of appropriate heating parameters can also help to obtain the specified thickness of the scale layer, thus to enable the predictability of the results of a given heating process. The "appropriate" heating process parameters are understood as the adjustment of the heating duration and temperature and such a composition of gaseous atmosphere that gives the obtained scale layer the assumed thickness [6]. A scale layer, even a thin one, makes an isolating layer for the heat transfer due to its low thermal conductivity. Within the porous charge heating region, the con-

tact heat conduction plays a key role, therefore, the oxidation phenomenon is crucial throughout the heat treatment process. The research on the scale layer thickness, which is described in the paper, constitutes an introduction to a doctoral thesis that deals with the heating of porous charge covered with an oxide film.

The literature concerned with heat exchange problems lacks information on the influence of the scale layer on the heat exchange process during heating charge of a porous nature. Examples of this type of charge can include:
- bundles of sections, flats, bars and tubes,
- coils of sheet, strip and wire rod,
- wire wound on a reel,
- small elements in bulk quantities, e.g. screws, nuts.

The conducted research is aimed at defining how the scale layer influences the heat exchange process in a bundle of steel rods and flats. For this purpose, it is necessary to analyze the scale formation process and to determine the heating parameters that assure a specific scale layer thickness to be achieved. When the thicknesses of scale layers forming on heating conducted according to calculated and assumed parameters are known, it will be possible to commence investigation to examine the heat exchange in the bed of steel elements covered with a scale layer.

THE HEATING PARAMETERS

The determination of the heating parameters is understood as the selection of the proper conditions under which the heating process is to be conducted. Due to the fact that heat treatment operations run at a high level of thermal energy consumption, the proper selection of heating parameters becomes a crucial issue. Efforts should, therefore, be made to optimize heat treatment processes by carefully selecting the heating parameters [7, 8]. The effect of the correct heating is a uniform temperature field on the entire cross-section of the treated element [9].

The most frequently applied methods of heating are:
- slow heating charge together from furnace,
- accelerated heating; charge places in furnace heating to suitable temperature,
- fast heating; charge places in furnace about initial higher temperature from the temperature required in the heating process.

The calculations of heating time for obtaining definite thickness of scale layer in work were executed, accepting following principles:
- thickness of scale layer $s = 1.5$ mm $= 0.0015$ m,
- temperature $t = 1100$ ºC,
- value of combustion air excess ratio $\alpha = 1.1$.

The thickness of scale layer is calculated using the relationship [1, 5]:

$$z = 356 \cdot \tau^{0,75} \cdot \alpha^{0,85} \cdot \exp\left[\frac{7500}{T}\right] \qquad (1)$$

From Equation (1), the following can be obtained from the heating time τ:

$$\tau = \sqrt[0,75]{\frac{z}{356 \cdot \alpha^{0,85} \cdot \exp\left[\dfrac{7500}{T}\right]}} \qquad (2)$$

The thickness of scale layer is calculated using the relationship [2,3]:

$$s = \frac{z}{\rho \cdot x_{Fe}} \qquad (3)$$

From Equation (3), we obtain:

$$z = s \cdot \rho \cdot x_{Fe} \qquad (4)$$

where: z – surface steel loss for scale, kg/m^2,
ρ – density of scale $\rho = 3900$ kg/m^3,
x_{Fe} – part of iron in the scale $x_{Fe} = 0.74$.

From here:
$z = 0.0015 \cdot 3900 \cdot 0.74 = 4.329$ kg/m^2

By substituting the data to the equation (2) the heating time τ is calculated using the relationship:

$$\tau = \sqrt[0,75]{\frac{4.329}{356 \cdot 1.1^{0,85} \cdot \exp\left[\dfrac{7500}{1373}\right]}} =$$

$$= 3.648 \text{ h} = 218.9 \text{ min}$$

THE TEST BENCH AND TESTING METHODOLOGY

The steel loss was determined using carbon steel St3S samples sized 30×30×50 mm, which were heated up in the furnace. Figure 1 presents the photos of samples. General view of heating stand is presented in Figure 2.

The basic element of the test bench is an electric furnace, type KS 520, with heating chamber dimensions of 220×220×520 mm. A combustion chamber with a gas burner are integrated with

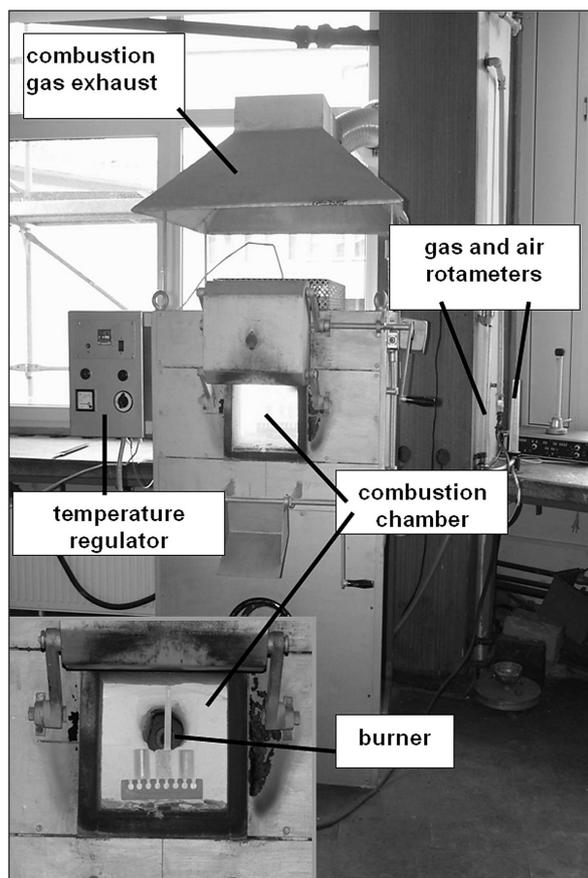**Fig. 1.** Carbon steel samples St3S, used for research

Fig. 2. General view of heating stand for steel samples, electric-gaseous furnace KS 520

the furnace. The burner performs the role of a gaseous atmosphere generator. The value of excess air ratio, and thus the chemical composition of combustion gas, is regulated in the burner. The remaining thermal power of the furnace is supplied in a form of electric power, which allows the temperature being precisely controlled at any location of the heating chamber of the furnace.

The temperature in the furnace is controlled with TROL – 9090 regulator. The accuracy of temperature control is ±1.0 K. The furnace chamber temperature is measured with PtRh-Pt control thermocouple and a three NiCr-Ni measuring thermocouple.

The supervisory sample was placed in the destination of temperature verification in the axis of steel charge, in the furnace chamber with thermocouple NiCr–Ni. The value of excess air ratio is controlled by continuous measurement of gas flow intensity and the air supplied to the burner. The intensity of gas and air flow is measured with rotameters. The flow of gas and air carried out suitably V_g = 0.488 m³/h, V_p = 5.0 m³/h. The analysis of combustion gas composition was conducted with the TESTO 350 analyzer. Result of measurements of combustion gas composition are summarized in Table 1.

Table 1. The composition of combustion gas in a research

| Component of combustion gas	Value	Individual
CO_2	10.8	%
O_2	2.0	%
NO	65.0	ppm
NO_x	68.0	ppm
CO	0	ppm

The investigation on three different methods was conducted:

- I method: The sample was placed in the furnace chamber and which was then heated to the temperature 1100 °C. Then it was heated for 3 hour 39 min.
- II method: The studied sample was inserted into the furnace chamber heated to the temperature 1100 °C. Then it was heating by 3 hour 39 min.
- III method: The sample was placed in the furnace chamber heated to obtain temperature 1100 °C in the axis of the sample. Then it was heating by 3 hour 39 min.

ANALYSIS OF RESULTS

The heating process was carried out for the assumed and calculated parameters. The aim of the undertaken tests was to verify the obtained scale layer thickness for the analytically determined heating parameters.

After leaving the heating unit, the heated samples were allowed to cool down. Scale that formed during the heating process for all of the
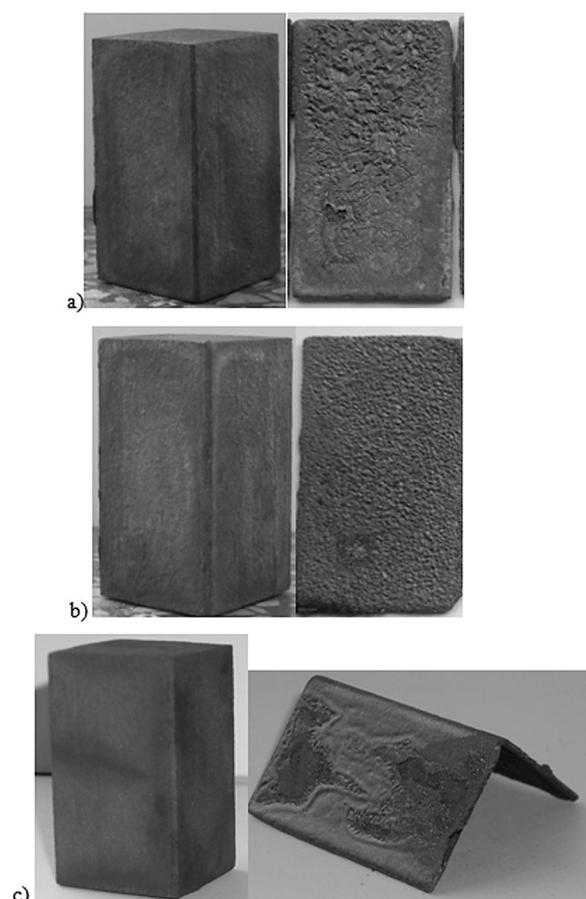
Fig. 3. Photographs illustrating the sample after heating and a layer of scale formed: a) I method, b) II method, c) III method

three methods came off from the steel substrate very easily, as shown in Figure 3.

The small adhesion caused ideal separation of scale layer from the sample surface. This permitted exact qualification of scale thickness. Measurements of the thickness of scale layer dimension were done with a micrometer with accuracy ± 0,01 mm.

The results of measurements of scale layer thickness, measured at three points on each side of the sample are summarized in Table 2.

By examining the final effect of the tests it could be concluded that the thickness of the scale layer formed in the process of heating according to method III attained the assumed value. For heating according to method I, a deviation of 0.15 mm from the assumed scale layer thickness was noted, while for heating by method II, a deviation of 0.23 was found.

These slight deviations from the assumed scale layer thickness are due to, among other things, the arrangement of the sample in the furnace, since the sample base that contacted the furnace bottom was distinguished by a thinner scale layer. This happens because this is the location where the access of the furnace atmosphere is more difficult. Moreover, it should be noted that the lowest scale layer thickness was obtained for heating method II. This is due to

Table 2. The values of the scale layer thickness

Number of the method	Place of measurement	Values of the thickness of scale layer, mm			
		Point 1	Point 2	Point 3	Value average
Method I	Side of sample 1	1.40	1.43	1.38	1.40
	Side of sample 2	1.41	1.32	1.29	1.34
	Side of sample 3	1.50	1.42	1.40	1.44
	Side of sample 4	1.41	1.32	1.30	1.34
	Basic of sample 1	1.50	1.40	1.20	1.36
	Basic of sample 2	1.25	1.18	1.20	1.21
	Value average				1.35
Method II	Side of sample 1	1.37	1.30	1.27	1.31
	Side of sample 2	1.35	1.31	1.30	1.32
	Side of sample 3	1.30	1.27	1.25	1.27
	Side of sample 4	1.31	1.26	1.27	1.28
	Basic of sample 1	1.36	1.25	1.22	1.27
	Basic of sample 2	1.20	1.10	1.15	1.15
	Value average				1,27
Method III	Side of sample 1	1.50	1.47	1.45	1.47
	Side of sample 2	1.50	1.50	1.51	1.50
	Side of sample 3	1.51	1.50	1.50	1.50
	Side of sample 4	1.50	1.49	1.48	1.49
	Basic of sample 1	1.50	1.49	1.47	1.48
	Basic of sample 2	1.48	1.41	1.40	1.43
	Value average				1,48

the fact that during heating according to method II the sample was held in the scale formation promoting temperature (above 900 °C) for much shorter time.

It should also be noted that in the case of heating according to methods I and II the furnace working temperature was 1100 °C; however, the temperature on the charge cross-section reached the value of 1064 °C. This slight difference could have also contributed to the deviations in the scale layer thickness values.

Heating conducted according to the assumptions of method III was aimed at eliminating the cross-section temperature difference. Therefore, the sample was heated until temperature of 1100 °C was obtained in the axis. With the use of this mode of heating it was found that the obtained scale layer thickness conformed the assumption.

SUMMARY

The results of the conducted tests indicate the possibility of using analytical relationships for modelling the thickness of the scale layer forming in the charge heating process. However, the sample heating method should be considered. The scale forming phenomenon might have a significant influence on the results of porous charge testing; therefore, allowing the charge oxidation process should be considered in the context of both experimental and model studies concerning this problem. This possibility will be exploited in the investigation of the heating of porous charge covered with a scale layer.

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