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Calculation of Measurement Errors in Research of Adhesion of Scale to the Steel Substrates for Cold Specimens

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Abstract : In experimental research, determining the potential measurement errors is an extremely important element. Also, the scale adhesion tests require such calculations. The paper presents the results of the scale adhesion tests for specific thermochemical parameters using the cold samples method. The calculation scheme and results of calculating measurement errors were also demonstrated.

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1 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 and slows down the heating process, but also adversely affects the service file of heating equipment. An important issue in the operation of heating furnaces is the adhesion of a scale layer to the surface of the steel being heated. Too high adhesion causes the scale not being completely removed from the surface of the heated charge and it is subsequently rolled into the surface of the product during the plastic working process. The removal of laps requires arduous and costly mechanical working [1÷3]. The problem of scale adhesion in heating process has been widely covered in publications [3÷10].

In scientific research, determining the value of measurement errors that can affect the quality of research is an extremely important element. The imperfections of the measuring apparatus, imperfections of observation and elusive influence of the environment may cause differences in the values of physical quantities determined by measurement and expressed by a specific number of units in relation to the actual value of this quantity. This difference is called an absolute error. The relative error of the measurement is equal to the ratio of the absolute error to the actual value [11].

There are many reasons for the magnitude of the measurement error. Depending on the type of cause and the nature of the error, it decides whether these are systematic or accidental errors [11÷17]. Systematic errors always affect in the same way the result of a measurement carried out using the same measuring apparatus and method of measurement. Random errors are the result of many small and variable random factors.

2 Measuring stand and research methodology

To realize the objective of the research, a specialized laboratory has been built at the Department of Production Management. A combustion chamber with a gas burner are integrated with 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 the form of electric power, which allows the temperature to be precisely controlled at any location of the heating chamber of the furnace. The temperature in the furnace is controlled by means of a TROL – 9090 regulator. The accuracy of temperature control is ±1.0K. The furnace chamber temperature is measured by means of a PtRh-Pt control thermocouple and a NiCr-Ni measuring thermocouple. The value of excess air ratio is controlled by the continuous measurement of the intensity of flow of gas and air supplied to the burner. The intensity of flow of gas and air is measured with rotameters [6÷8]. A schematic diagram of the furnace is shown in Figure 1.

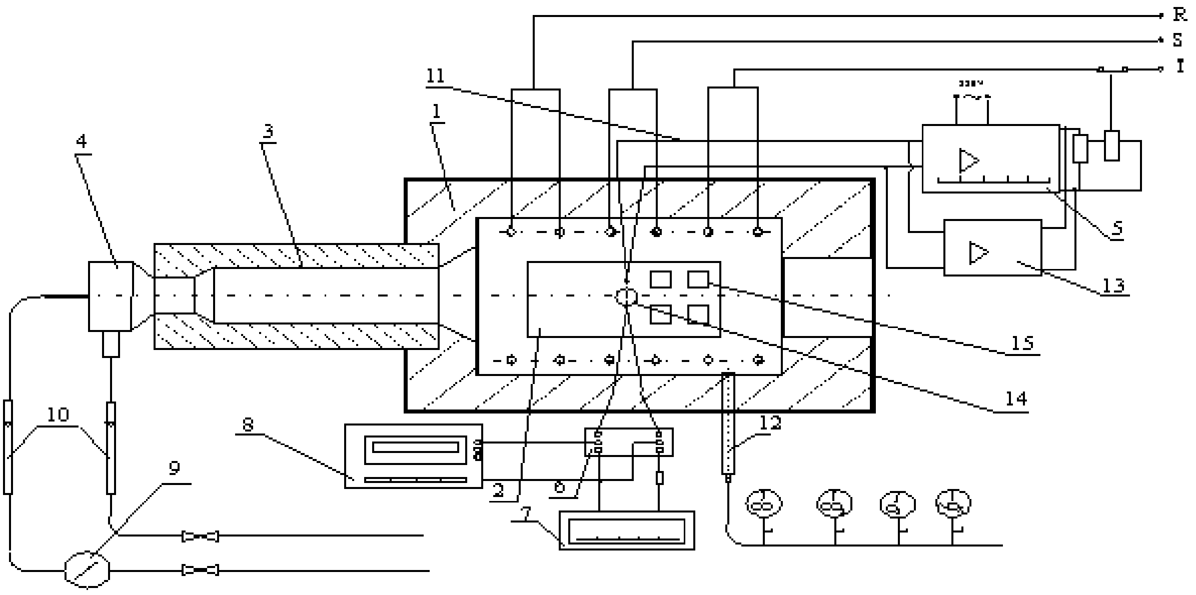

Figure 1 Schematic diagram of an electric&gas furnace [6, 18]

1 - furnace, 2 - refractory stand, 3 - combustion chamber, 4 - burner, 5 - temperature regulator, 6 - compensation box, 7 - temperature recorder, 8 - milivoltmeter, 9 - gas meter, 10 - rotameters, 11 - PtRh-Pt control thermocouple, 12 - combustion-gas drawing probe, 13 - programmable temperature controller, 14 - test specimen with a NiCr-Ni thermocouple, 15 - specimens tested

Measurements, for cold samples, were performed by measuring the force needed for detaching the scale layer and then by calculating the adherence (P_z) expressed in MPa.
The value of the scale adhesion for cold method is defined by the following relationship:

$$P_z = \frac{Q_r}{A_{cz}} \cdot 10^{-6} \qquad (1)$$

where:
P_z - scale adhesion for cold method, (MPa),
Q_r - value of force needed, (N),
A_{cz} - field of surface of researched foremost sample, (m^2).

It should be noted that the direct adhesion measurements were preceded by cooling the samples down to ambient temperature, followed by joining the formed scale with reference samples using a glue of an appropriate tensile strength. The method applied to the testing of scale adhesion to the cold charge is a quantitative method allowing the numerical determination of the force that bounds the scale with the steel core. The value of force needed for detaching the scale layer from the steel surface was measured by using a TC-FR100TL.A4K testing machine [6]. Scheme of course research present on Figure 2. Scheme of testing machine present on Figure 3.

3 Results of adhesion measurements

It carry measurements of masses of samples in the successive stages of the test. Calculation of scale adhesion on the base of carried measurements was executed. The heating were varied out with the value of combustion air excess ratio of α=0.6÷1.4. and heated in temperature 900, 1000, 1100, 1200 and 1300°C. Results of measurements and accounts summarized in Table 1 and Table 2.

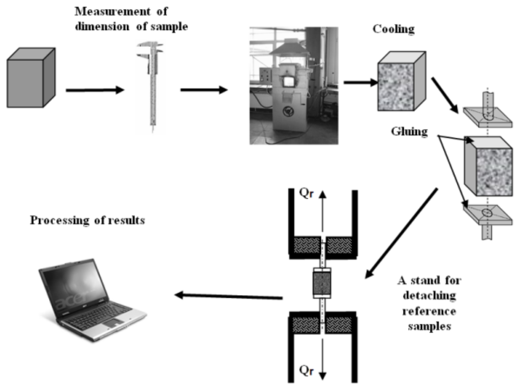

Figure 2 Scheme of course research of the scale adhesion [6]

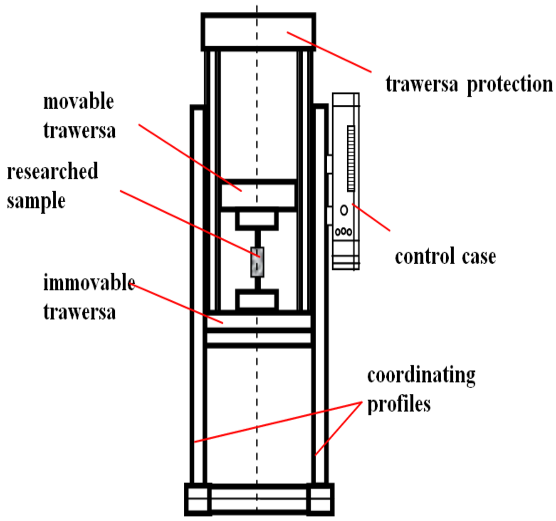

Figure 3 Scheme of testing machine

Table 1 The results of the measurements of scale adhesion P_z (MPa) for $\alpha \leq 1.0$

Temperature t [°C]	**Value of combustion air excess ratio α**				
	0.6	0.7	0.8	0.9	1
900	0.545	0.646	0.748	0.852	0.956
1000	0.963	1.142	1.322	1.505	1.690
1100	1.567	1.857	2.150	2.448	2.749
1200	2.386	2.826	3.274	3.726	4.184
1300	3.443	4.079	4.724	5.378	6.038
1330	3.809	4.513	5.227	5.950	6.682

Table 2 The results of the measurements of scale adhesion P_z (MPa) for $\alpha > 1.0$

Temperature t [°C]	**Value of combustion air excess ratio α**			
	1.1	1.2	1.3	1.4
900	1.085	1.169	1.251	1.332
1000	1.794	1.931	2.067	2.202
1100	2.755	2.966	3.175	3.381
1200	3.991	4.298	4.600	4.899
1300	5.517	5.941	6.359	6.772
1330	6.032	6.495	6.952	7.404

4 Analysis of measurement errors

In the paper in the presented research, the cause of systematic errors can be:

- measurements of dimensions sample, $\pm 10^{-5}$ m,
- measurements of the heating time, ±10 s,
- accuracy of the temperature control, ±1K,
- accuracy of regulation of gas and air flow, $\pm 10^{-2}$ $m^3.h^{-1}$.

To calculate ΔP_z, for the scale adhesion determined by the cold method, the equation (1) should be written in the form:

$$\Delta P_z = \left|\frac{\partial P_z}{\partial Q_r}\right| \cdot |\Delta Q_r| + \left|\frac{\partial P_z}{\partial A_{cz}}\right| \cdot |\Delta A_{cz}| \qquad \text{[Pa]} \quad (2)$$

where:

$\Delta Q_r = \pm$ 1N.

The value of ΔA_{cz} was calculated by means of the absolute differential method from the dependence on the surface of the squere:

$$\Delta A_{cz} = \left|\frac{\partial A_{cz}}{\partial a}\right| \cdot |\Delta a| \qquad [m^2] \qquad (3)$$

After differentiation, we received:

$$\Delta A_{cz} = 2 \cdot a \cdot |\Delta a| = \pm 6 \cdot 10^{-6} \ m^2 \qquad (4)$$

Differentiating and substituting the results of calculations for the relationship (2) was obtained:

$$\Delta P_z = \frac{1}{A_{cz}} \cdot |\Delta Q_r| + \left(-\frac{Q_r}{A_{cz}^2}\right) \cdot |\Delta A_{cz}| = \pm 57 \text{ Pa} \qquad (5)$$

The average value of the adhesion measure will be:

$$\overline{P_z} = \frac{\sum_{i=1}^{n} P_z}{n} = \frac{181.747}{54} = 3.366 \text{ MPa} \qquad (6)$$

The average value of a relative systematic error is:

$$\delta_z = \frac{\Delta P_z}{\overline{P_z}} \cdot 100\% = 0.0017\ \% \qquad (7)$$

5 Conclusions

The accuracy of measurements can also be affected by accidental errors to which, in the case of the presented research, can be included:

- changes in ambient parameters,
- fluctuations in the chemical composition of the gas,
- fluctuations in gas pressure,
- fluctuations in air pressure,
- other.

Analyzing the obtained values of absolute statistical error and average relative error, it can be concluded that the measurement of the adhesion of the scale to the steel substrate for cold method has been carried out with high accuracy.

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