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THE EFFECT OF CONDITION OF THE CHARGE SURFACE ON THE SCALE ADHESION FOR EXCESS AIR COMBUSTION

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In the process of heating steel the processes of chemical interaction occur between the furnace atmosphere and the surface of the steel being heated. Great importance, in aspect of course of the oxidizing process equal as well as for phenomenon of scale adhesion on the charge surface, condition of his surface has. Roughness is parameter defining condition of surface. The methodology of investigations of scale adhesion in work was presented. The methodology of measurement of roughness surface was introduced. Influence of surface roughness on the scale adhesion was described. The paper presents correlation of the scale adhesion but roughness of surface.

Key words: heating, oxidation, surface, adhesion, scale

INTRODUCTION

In numerous instances, the process of oxidation is dependent on the condition of the metallic phase surface. This condition is determined by the following factors [1–3]:

- the crystallographic orientation of the metal surface contacting the oxidation medium, and then the reaction product,
- the physicochemical condition of the surface, being dependent on its treatment and interaction with the external environment until the moment of starting of the proper oxidation process,
- surface microgeometry, as defined by the dimensions and shape of irregularities that also depend on the surface treatment.

The influence of these factors has been scarcely taken into account in studies and in the interpretation of experimental results, and is underestimated by practitioners.

In the case of formation of tarnish films or in the initial phase of rapidly proceeding reactions, the abovementioned changes in surface condition will result in a disturbance of the nucleation and orderly reaction product build-up. It is likely that there is also a dependence of oxidation rate on the size of the actual surface area which is a function of microgeometry.

Eubanks, Moore and Pennington [4] carried out extensive studies on the effect of surface microgeometry on the oxidation rate and the structure of oxide scale on iron. Tests within the studies under consideration were carried out in air at a temperature of 800 °C. The starting materials in the tests were specimens of rolled ingot iron which, after heat treatment, were subjected to abrasive blasting with various abrasives. The following abrasives were used: silicon, silicon carbide, alumina and iron shot of the same origin as that of the specimens of the metal being treated. The latter abrasive was used in the form of very small cubes. After the treatment, the specimens were ultrasonically cleaned in acetone in order to remove any residues of the abrasive. To remove the stresses formed on the specimen surface during sand blasting, the specimens were annealed in a hydrogen atmosphere and then in vacuum.

Oxidation rate measurements have shown that the process runs in principal following the parabolic law, irrespective of the type of surface treatment. Significant differences occur, however, in the process rate. All specimens subjected to sand blasting showed a lower reaction rate compared to the specimens with the original surface. The reaction rate reduction effect cannot be associated in this case with surface contamination, as the specimen blasted with iron shots also exhibited a lower oxidation rate [5,6]. The authors of the study under discussion ascribe the identified reaction rate differences to the change in surface geometry that occurred during the treatment of the specimens with abrasives.

The surface microgeometry has also a clear impact on the structure and phase composition of scales.

The conducted investigation provides an incentive for deliberation on the effect of surface condition on the adherence of scale.

MEASURING STAND AND TESTING METHODOLOGY

To realize the objective of the study, a specialized laboratory has been built at the KPPiOŚ (Department of Industrial Furnaces and Environmental Protection). The basic element of the testing stand is an electric furnace,

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type KS 520. A combustion chamber with a gas burner is integrated with the furnace. The burner performs the role of a gaseous atmosphere generator. The temperature in the furnace is controlled by means of a TROL – 9090 regulator. The accuracy of temperature control is ± 1,0K. In order to determine the adhesion of scale for mass method, a scale knocking-off device was designed and constructed. A set of testing stands discuss in work more widely.

It takes advantage mass method for research of influences the condition of charge surface on the scale adhesion.

It was assumed that the degree of specimen surface cleaning after partial chipping off of the scale layer would be essential for the measurement. The mass method of determining the adhesion of scale involves the weighting of specimens in the successive stages of the test [7].

The adhesion of a scale layer can be expressed by the ratio of the mass of scale left after knocking off to the entire mass of the scale. The value of so determined adhesion is defined by the following relationship [8]:

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

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

The masses m_2 and m_3 are determined by weighting the specimens. For the determination of the mass m_1, the following relationship is used:

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

where: m_0 – mass of the specimen before heating / kg, z – loss of steel for scale / kg/m^2, A – specimen surface area / m^2, x_{Fe} – elementary iron mass fraction of the scale.

For the determination of the loss of steel, the following relationship is used:

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

The measurements of surface roughness were carried out using an HOMMEL T1000 portable instrument.

This instrument, coupled with an LV16 drive unit, makes it possible to measure surface roughness and to obtain data on waviness and profile, according to DIN and ISO standards.

Its ergonomic housing incorporates a graphic display and a robust keypad. It comes with 5 measurements programs operating with a computer unit, which assure quick taking of measurements and storing obtained results in a database.

The mechanical tracking of a surface shape by the HOMMEL T1000 instrument is done using a moving induction transducer. In this system, a diamond tip is guided over the surface being measured. The tip is connected to a head armature that is positioned horizontally in relation to the scanned surface with a fulcrum.

On the top of the armature, there are two ferrite plates. With a neutral head position, the distance between these plates and the two coils installed within the head housing is equal. Sinusoidal voltage, called the carrying voltage, is supplied to the coils. A change in tip position occurring during tip movement over the rough surface causes a change in the inductance of the coils.

The resulting voltage variations are evaluated by the head electronics and transformed into a signal proportional to the changes in tip position, and then sent to the computer unit.

RESULTS OF MEASUREMENTS OF THE SCALE ADHESION AND ROUGHNESS SURFACE

It prepares samples within the confines of research about different condition of surface. It present photos of surfaces samples on Figure 1.

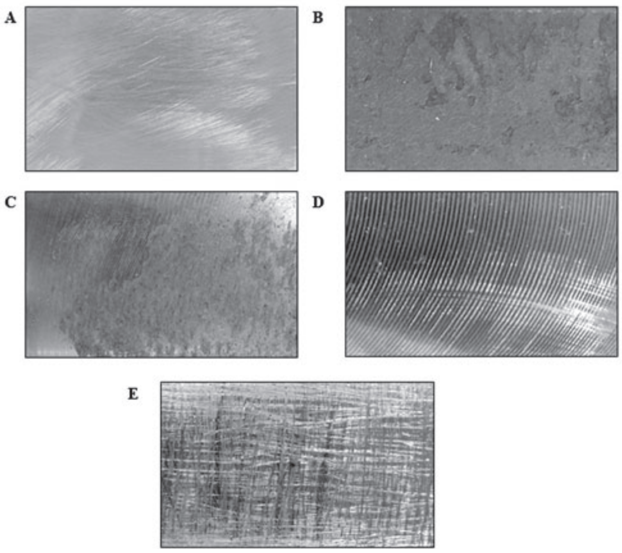

Figure 1 The photos of surfaces samples. A- ground sample, B- raw sample, C-sample ground and then exposed to moisture, D- milled sample, E- cross-incised sample

It carries measurements of roughness of surfaces samples. Results of measurements of roughness are summarized in Table 1.

Table 1 **Results of measurements of roughness**

Designation of sample	The arithmetical mean roughness profile, R_a / μm	The roughness height, R_z / μm	Maximum height of roughness, R_m / μm	Maximum height of elevation-depression, R_t / μm
A	0,53	3,36	4,02	4,26
B	4,18	19,61	34,57	34,57
C	1,05	9,37	13,36	15,18
D	8,49	30,84	32,52	33,54
E	4,09	25,17	36,86	36,86

From the surface condition tests carried out with the HOMMEL T1000 instrument it can be found that Specimen A (ground) has the smoothest surface, i.e. is characterized by the lowest surface roughness. Specimen C (ground and then exposed to moisture) has the highest surface coarseness, which indicates that corrosion impacts on the condition of metal surface. Specimen B (raw) shows significant deviations in roughness profile of 4,18 μm and in roughness height of 19,61 μm. The largest deviations and roughness can be observed on Specimens D (milled) and E (cross-incised).

The heating of specimens was carried out for the temperature t = 1 100 °C and for the excess combustion air ratios α = 1,2. The specimen heating time was τ = 2 h. Results of accounts are summarized in Table 2.

Table 2 **Results of accounts of loss of steel and scale adhesion**

Designation of sample	Loss of steel, z / kg/m²	Scale adhesion, P / %
A	4,422	9,87
B	3,855	25,55
C	3,670	13,55
D	3,793	33,99
E	3,751	28,66

Considering of the scale adhesion in the aspect of surface condition it can be stated that the poorer specimen surface condition, the greater scale adhesion. Based on the measurements and calculations, a close relationship is found to exist between surface roughness and scale adhesion.

THE EFFECT ANALYSIS OF ROUGHNESS SURFACE ON THE ADHESION

The analysis of influence of roughness surface on the scale adhesion to the steel substrate on the base of carried measurements and accounts was executed. The scale adhesion as function of roughness surface was described. For the analysis, the values of R_a and R_z were used as parameters characterizing surface roughness being the measure of surface condition. Several computer simulations were performed to approximate mathematical functions that could describe that effect.

It analyze values of statistic errors and capabilities of employment of functions for mathematical consideration related with scale adhesion. It was established that dependence of scale adhesion P from R_a is possible to describe function:

$$P = 14{,}0368 \cdot R_a^{0{,}43} \quad (4)$$

and from R_z is possible to describe function:

$$P = 6{,}3497 + 0{,}904 \cdot R_z \quad (5)$$

Accounts of values of empirical ratios and values of statistic errors were executed. Effect of the arithmetical

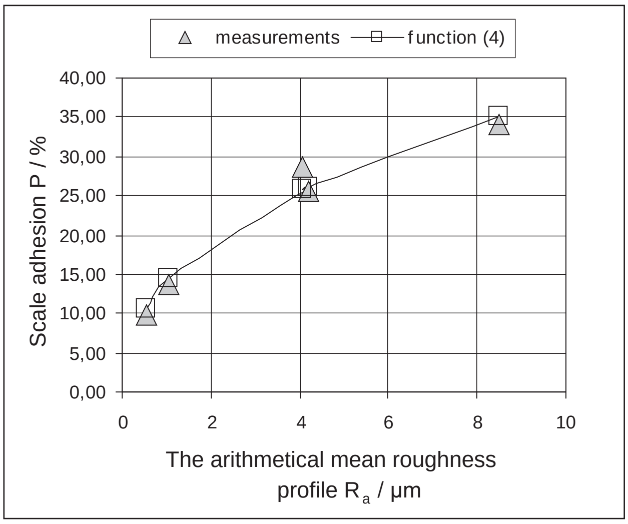

Figure 2 Effect of the arithmetical mean roughness profile on the scale adhesion

Table 3 **The result of account of the scale adhesion and values of statistic errors**

Designation of sample	The arithmetical mean roughness profile, R_a / μm	Scale adhesion (measurements), P / %	Scale adhesion (function), P / %	Value of the correlation coefficient R^2	Mean error of approximation δ / %
A	0,53	9,87	10,68	0,986	5,9
C	1,05	13,55	14,33		
B	4,18	25,55	25,96		
E	4,09	28,66	25,70		
D	8,49	33,99	35,21		

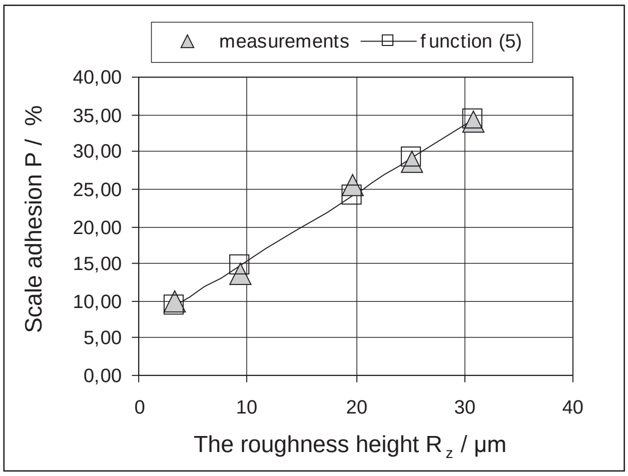

Figure 3 Effect of the roughness height on the scale adhesion

Table 4 **The result of account of the scale adhesion and values of statistic errors**

Designation of sample	The roughness height, R_z / μm	Scale adhesion (measurements), P / %	Scale adhesion (function), P / %	Value of the correlation coefficient R^2	Mean error of approximation, δ %
A	3,36	9,87	9,39	0,995	4,5
C	9,37	13,55	14,82		
B	19,61	25,55	24,08		
E	25,17	28,66	29,10		
D	30,84	33,99	34,23		

mean roughness profile (R_a) on the scale adhesion show in Figure 2. Results of accounts and values of statistic errors are summarized in Table 3.

Effect of the roughness height (R_z) on the scale adhesion shows in Figure 3. Results of accounts and values of statistic errors are summarized in Table 4.

Served dependences have become describing influence of the surface condition on the scale adhesion characterized of high correlation coefficient and small mean error of approximation. It testifies about correctness of accept mathematical function.

CONCLUSIONS

The performed laboratory tests and the accounts carried out allow the following conclusions to be drawn:

- Surface condition, besides the heating parameters, has a substantial influence on the scale adhesion to the steel substrate.
- The highest adherence values were obtained for Specimen D with the greatest surface irregularities.
- With the increase in the arithmetical mean roughness profile, the scale adhesion increases.
- With increasing roughness height, the scale adhesion increases.
- The effect of the arithmetical mean roughness (R_a) on the scale adhesion can be described with a high accuracy using power function.
- The effect of the roughness height (R_z) on the scale adhesion can be described with a high accuracy using linear function.
- The analysis of the effect of surface condition on the adhesion, while allowing for the effect of heating parameters, can provide a substantial input to the development of a heating technology that will assure the optimal scale adhesion.

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Note: The professional translator for English language is Czesław Grochowina, Studio-Tekst, Poland.