

EXPERIMENTAL MEASUREMENTS OF SCALE ADHESION FOR A PRE-OXIDIZED STEEL CHARGE

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Preliminary Note – Prethodno priopćenje

In industrial practice, the charge is heated before the forming process and often reaches the furnace "cold". This means that after leaving the continuous casting of steel, for various reasons it is not heated immediately, but stored instead. This causes not only the cooling of the charge but also its oxidation in the atmosphere of the surrounding air. The paper presents the research methodology and discusses the results of adhesion measurements for a pre-oxidized steel charge.

Keywords: steel charge, heating, oxidation, pre-oxidized steel, measuring

INTRODUCTION

Scale is a product of an oxidation reaction, usually formed on the surface of a metal or an alloy. As a rule, metal oxidation produces solid oxidation products over a wide range of temperatures.

Scale most often has a multilayer structure. A certain regularity has been observed in that the outer layer of scale is generally compact and the inner layer is porous. This may indicate that, within the outer layer, the scale is a compact polycrystallite. The reacting substrates are therefore separated by a continuous layer of product from the start of the oxidation process. At low temperatures, this means that the reaction is almost completely inhibited. At elevated and high temperatures, the oxidation process continues thanks to the diffusion one or both of the reacting substrates through the product layer.

Oxidation is a complex process that consists of many elementary, interrelated processes. The decisive role in the process of oxidation of metals and alloys is played by the diffusion of reagents in the scale, which is one of the slowest partial processes that determine the speed of the total reaction. A layer of the reaction product usually inhibits the speed of the oxidation process [1-3].

The oxidation process itself depends mainly on the processes of transport of the mass in the scale. These processes can take place through the crystalline network, along the grain boundaries or through macrodefects (cracks and crevices). In the case of oxidation of a clean metal surface, formation of scale is preceded by successive elementary processes:

- physical adsorption of gas;
- chemisorption; and

- Qconversion of a layer of chemisorbed oxygen into a layer of oxides.

These processes, especially at low temperatures, have a significant impact on the course and speed of the reaction at the later stage of oxidation [1, 2].

The issue of adhesion of scale to the substrate is of great technological importance both in the rolling process and in the heat treatment of steel charges. Scale with high adhesion is difficult to remove and its residues on the core cause deterioration of rolled or heat treated products. This problem is also suggested by the authors of the publication [4 -7].

Scale characterized by low adhesion to the substrate is easily detached, thus allowing the attacking gas to directly access the surface of the core or the closer layers of the reaction product. Under these conditions, secondary scale formation occurs. Scale that is falling off also causes mechanical damage to the refractory lining of the bottoms of the heating units, which leads to frequent shutdowns and reduced efficiency [1].

The production process in rolling mills depends on the fulfillment of orders; therefore, the production plan is subordinated to the current needs of the customers and not to the availability of hot charges from the continuous casting of steel line. Consequently, hot billets are often put into storage waiting to be heated according to the order plan. This causes loss of enthalpy in the charge, but also exposes the steel to oxidation in the surrounding air.

In this paper, the impact of preliminary oxidation of steel charges on adhesion of scale to the steel substrate is analyzed.

MEASUREMENT STAND AND RESEARCH METHODS

Scale adhesion tests were carried out on a special stand described in the publications [1, 8]. Scale adhe-

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sion was determined using the mass method. It was expressed as the ratio of the weight of the scale remaining after descaling to the total weight of the scale [1]:

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

where:

m_1 - weight of the sample after heating/ g,

m_2 - weight of the sample after descaling/ g,

m_3 - weight of the sample after total cleaning/ g,

P - the measure of scale adhesion, determined by the percentage of the scale remaining on the steel core after the impact of the rammer/ %.

The impact of oxidation of the charge, before it was put in the furnace, on the adhesion of the scale was measured and analyzed. The tests were performed on cylindrical samples ($d = 34$ mm, $h = 50$ mm) that were preoxidized by preheating in an air atmosphere at $1\ 200$ °C for the time of $\tau = 1$ h. A photo of the face surface of a sample preoxidized in air is shown in Figure 1.

Two layers of scale were formed on the surface of the sample and were slightly bound to the metal surface. The outer layer was about 0,6 mm thick and the inner layer was about 0,25 mm thick. The first layer fell off the surface after the sample cooled down or immediately during an attempt to put it back in the furnace.

Next, adhesion measurements were performed for samples heated at 900, 1 000, 1 100, 1 200, 1 300, and 1 330 °C, with the value of combustion air excess ratio equal to $\alpha = 0,8$ and $\alpha = 1,2$. The heating time was $\tau = 2$ h. The measurement methodology is shown in Figure 2.

In selected cases, additional samples were heated to illustrate the sample surface after the heating. Figure 3 shows photos of face surfaces of samples heated at different temperatures with the value of excess combustion air ratio equal to $\alpha = 0,8$.

In the case of samples oxidized in the flue gas resulting from combustion of gas with $\alpha = 0,8$, a multilayer scale characterized by a dark color and small thickness was formed. It did not fall off when the sample was taken out of the furnace. Figure 4 shows photographs of face surfaces of samples heated at different temperatures with the value of excess combustion air ratio equal to $\alpha = 1,2$.

In the case of samples oxidized in the flue gas resulting from combustion of gas with $\alpha = 1,2$, a multilayer scale characterized by a clearly metallic gloss and significant thickness was formed. After the samples were re-



Figure 1 A photo of the face of a sample preoxidized in air

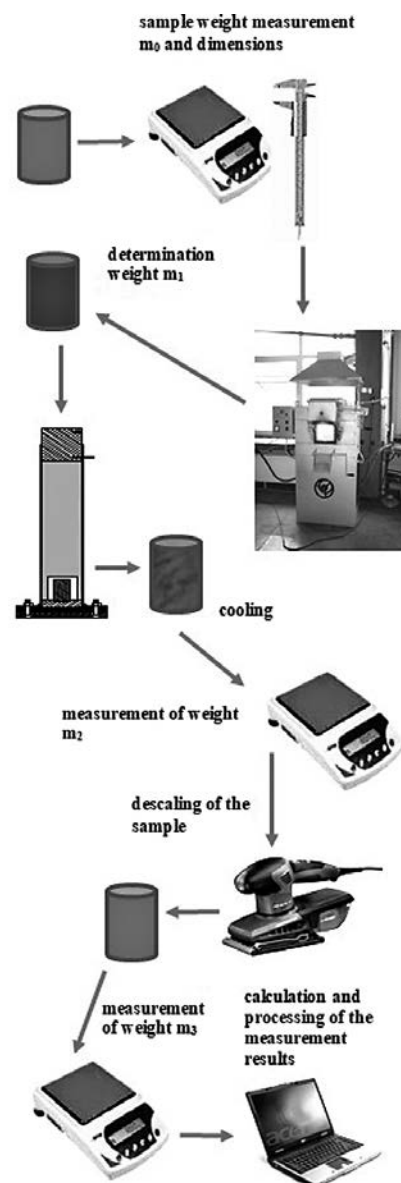


Figure 2 A diagram showing the course of the adhesion tests performed using the mass method [1, 8]

moved from the furnace, the outer layer of the scale, probably the residue from the scale formed in the air, fell off.

MEASUREMENT RESULTS

For the assumed parameters, heating was carried out on the samples. Measurements and calculations of scale adhesion to the steel substrate were performed. The results are shown in Figures 5 and 6.

SUMMARY

The measurements showed that the adhesion of the scale to the steel substrate is much higher than the mutual adhesion of the individual layers of the scale. In addition, significantly lower adhesion was observed for the samples heated with both excess and insufficient combustion air which were subjected to preoxidation.

The samples heated with excess combustion air were characterized by lower adhesion of the scale to the

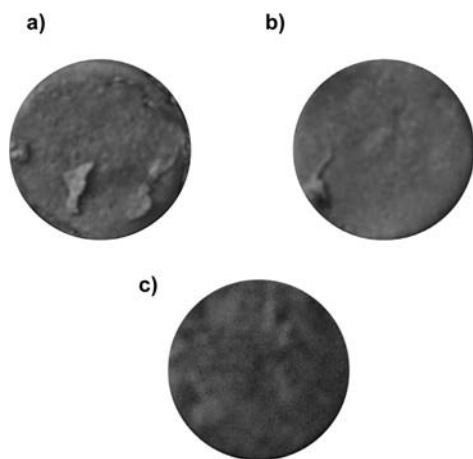


Figure 3 Photographs of sample face surfaces for $\alpha = 0,8$
a) $t = 1\,330\text{ °C}$, b) $t = 1\,300\text{ °C}$, c) $t = 1\,200\text{ °C}$

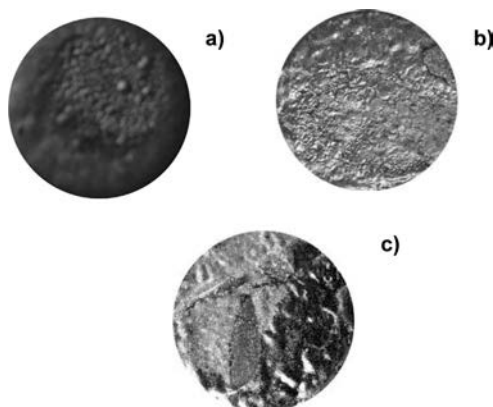


Figure 4 Photographs of sample face surfaces for $\alpha = 1,2$
a) $t = 1\,330\text{ °C}$, b) $t = 1\,300\text{ °C}$, c) $t = 1\,200\text{ °C}$

steel substrate than those heated with excess air, both pre-oxidized and not.

It was observed that scale adhesion for the pre-oxidized samples was 3 to 4 times lower for samples not oxidized in air, with the exception of the samples heated at the lowest temperatures. At temperatures of 900 and 1 000 °C, the scale fell off completely from the surface and, consequently, its adhesion was estimated at 0 %.

On the basis of the tests, it can be concluded that preliminary oxidation of a charge, i.e. not heating it up immediately after it is taken out of the continuous casting of steel, is unfavorable due to the operation of heating furnaces. The charge may then have low adhesion of scale during the heating process, which causes the scale to fall off in the furnace, contaminate the bottom, and possibly damage it. In addition, it will make it necessary to increase the frequency of cleaning of the space under the bottom in the furnace to remove scale.

This can be seen as another argument, in addition to lower fuel consumption and reduction of pollution, for efforts to heat up the hot charge.

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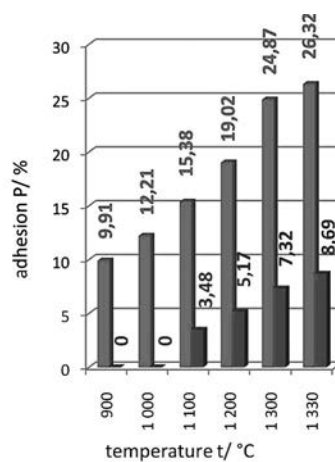


Figure 5 Results of the measurements of scale adhesion for non-oxidized and preoxidized samples for the excess air ratio equal to $\alpha = 0,8$

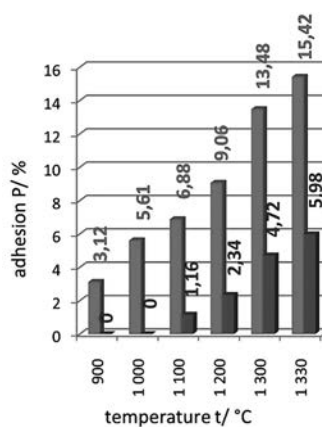


Figure 6 The results of the measurements of scale adhesion for non-oxidized and preoxidized samples for the excess air ratio equal to $\alpha = 1,2$

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Note: The responsible translator for English language is Martyna Fatel, LinguaLab, Kraków, Poland