CORROSION BEHAVIOUR OF CHOSEN CONSTRUCTION METALS IN THE DUCT SYSTEM OF THE RECYCLING ALUMINIUM FURNACE

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Abstract

The corrosion behaviour of five types of steels and cast irons proposed for production of the duct system in the recycling aluminium furnace is studied in this article. The metals tested were exposed in the real conditions at high temperature (from 800 to 1100°C) in very aggressive environment of combustion products for thirty days. The character and intensity of corrosion attack of the tested materials are evaluated by gravimetric and metallographic analysis.

Keywords: High temperature corrosion, Intergranular corrosion, Duct system.

1. Introduction

The duct system in the recycling aluminium furnace is a very aggressive medium from corrosion point of view. The aluminium waste which is reclaimed contains remains of various materials (oxygen, carbon oxides, steam, sulphides, halides etc.) according to the character of Al waste. It means that the environment is changed and its composition cannot be defined exactly. Therefore it is difficult to define character of working medium and predict corrosion behavior of construction metal. Corrosion rate of metals is expressly influenced by temperature and by character of corrosion products which are formed by reaction. The suppose temperature in the duct system is ranging from 800 °C to 1100 °C. This temperature range is important because temperature governs kinetics of corrosion reaction and character of corrosion products too. Also structural changes of materials can occur in these conditions (e.g. precipitation of carbides in stainless steels increases sensitization to intergranular, decarburization of surface layers in unalloyed material [1-3].

The chemical composition of environment is responsible for character of resultant corrosion products. Present oxygen in work environment creates with Fe alloys (low or high alloyed) oxides mostly with protective character and especially with the elements Cr, Al, Si. The sulphur compounds (H₂S, SO₂) are unwanted because sulphides do not have protective properties, create eutectics and increase corrosion rate. Halides (HCl, HF) freeing during Al waste combustion are very aggressive corrosive agents and support corrosive effect of sulphur compounds [4-6]. Besides the mention agents during the reclaim process the other components are produced (oxides of carbon and nitrogen, dust gases, organic compounds e.g. (VOC - volatile organic compound, dioxin) which increase corrosion aggressiveness of the work environment. The next factors affecting corrosion and mechanical properties of Fe alloys in the duct system are hydrogen, CO, hydrocarbons [4, 6].

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2. Experimental

Because of impossibility to specify exactly the chemical composition of the work environment in the duct system of recycling Al furniture [6], five types of Fe alloys were tested in the real duct system conditions. The experimental material was chosen according to actual references and experiences of operator and its chemical composition can be found in the Table 1.

**Experimental specification**

The experimental samples were fastening to the wall of the duct system and expose 30 days during the Al furniture real operation. Before the experiment the samples were mechanically cleaned, ungreased by ether and after drying weighed with the accuracy $10^{-5}$ g. One part of samples was situated on the duct system inlet site (the samples marked B) and the other part of samples was situated on the duct system exit site.

**Chemical composition of the tested Fe alloys**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Mg</th>
<th>Cu</th>
<th>Mn</th>
<th>N</th>
<th>Ti</th>
<th>C</th>
<th>Si</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1</td>
<td>17.20</td>
<td>8-11</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>0.12</td>
<td>1</td>
<td>0.045</td>
<td>0.03</td>
</tr>
<tr>
<td>No.2</td>
<td>16.87</td>
<td>9.9</td>
<td>0.16</td>
<td></td>
<td></td>
<td>1.49</td>
<td>0.011</td>
<td>0.49</td>
<td>0.08</td>
<td>0.52</td>
<td>0.027</td>
<td>0.19</td>
</tr>
<tr>
<td>No.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.009</td>
<td>0.17</td>
<td></td>
<td>&gt;0.045</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.4</td>
<td>0.07</td>
<td>0.45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.3</td>
<td>2.7</td>
<td>0.08</td>
<td>0.017</td>
</tr>
<tr>
<td>No.5</td>
<td>0.07</td>
<td>0.45</td>
<td></td>
<td>0.052</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td>3.3</td>
<td>2.7</td>
<td>0.08</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Fig. 1 The real time course of the gas combustion temperature in the duct system

Fig. 2. The surface of B and T samples after 30 days exposition
(the samples marked T). The real temperature course during operation in the duct system is in Figure 1.

**Experimental results**

After 30 days of exposition in the duct system the sample was covered by deposits as it can be seen in Fig.2 (on the inlet side 3 - 5 mm thickness and on the exit site about 1 mm).

It means that on the both sites of the duct system the different temperature condition and character of environment are proved. The deposits from the samples were mechanically removed and the corrosion products were chemically eliminated in the solution of the 20% HCl + 3.5 g hexamethylenetetramine per dm³ of the solution for 3 minutes at temperature of 22 °C. The cleaned and dried samples were weighted again. From the weight differences before and after exposition the weight losses per the area were calculated (\(v_k\)) and the reduction of material thickness too. The results are presented in Table 2.

Besides the weight analysis the thickness of corrosion attack was evaluated by metallographical microscopy.

The samples were cross-cut, sealed to resin, grinded, polished and etched. On the prepared samples the structure, character and intensity of corrosion attack are investigated. The differences in results of the corrosion attack depth calculated from weight loss and determined the one by microscopy are caused by different type of corrosion of the tested metals. The austenitic stainless steels have low weight losses but the real corrosion attack is deeper, because of the intergranular corrosion as it is explained in Fig 3.

The corrosion attack after 30 days exposition in the furnace was investigated on the etched samples (the unalloyed steel and cast irons by the Nital, the samples 1 by the Rollings (CuCl₂ + HCl+ethanol/, the samples 2 by the BR HNO₃+HF+glycerin).

![Fig. 3. Scheme of corrosion damage by intergranural corrosion](image)

The sample 1 is the austenitic steel with enhanced Cr content (the chemical composition in the Table 1) which can be used at high temperature. The steel structure, intensity and character of the corrosion attack after 30 days

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**Tab. 2**

<table>
<thead>
<tr>
<th>Sample</th>
<th>(v_k) (g·cm⁻²)</th>
<th>weight loss (µm)</th>
<th>Metallography (µm)</th>
<th>total depth (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1B</td>
<td>0.0126</td>
<td>16.1</td>
<td>cca 50</td>
<td>66.1</td>
</tr>
<tr>
<td>1T</td>
<td>0.0091</td>
<td>11.6</td>
<td>cca 50</td>
<td>61.1</td>
</tr>
<tr>
<td>2B</td>
<td>0.0244</td>
<td>31.2</td>
<td>cca 75</td>
<td>106.2</td>
</tr>
<tr>
<td>2T</td>
<td>0.0128</td>
<td>16.4</td>
<td>cca 150</td>
<td>166.4</td>
</tr>
<tr>
<td>3B</td>
<td>0.0594</td>
<td>76.1</td>
<td>cca 20</td>
<td>96.1</td>
</tr>
<tr>
<td>3T</td>
<td>0.0451</td>
<td>57.8</td>
<td>cca 20</td>
<td>77.8</td>
</tr>
<tr>
<td>4B</td>
<td>0.0814</td>
<td>104.3</td>
<td>cca 75</td>
<td>179.3</td>
</tr>
<tr>
<td>4T</td>
<td>0.0588</td>
<td>75.4</td>
<td>cca 75</td>
<td>150.4</td>
</tr>
<tr>
<td>5B</td>
<td>0.1004</td>
<td>129.0</td>
<td>cca 35</td>
<td>164.0</td>
</tr>
<tr>
<td>5T</td>
<td>0.0488</td>
<td>62.6</td>
<td>cca 35</td>
<td>98.2</td>
</tr>
</tbody>
</table>
exposition is showed in the Fig. 4. On the duct system inlet site (T sample) it is intensive general corrosion started on the grain boundaries and defluxion of the metal grains.

On the exit site the intergranular corrosion is observed. The corrosion attack reaches about 50 µm on the both sides. The chromium oxides do not protect the tested austenitic stainless steel against corrosion in the furnace conditions.

The next tested sample is austenitic stainless steel stabilized by Ti (chemical composition in the Table 2). The both investigated sites are attacked by intergranular corrosion. The intensity of corrosion is greater in comparison with the steel with higher Cr content according to the weight losses and metallographical microscopy too. Corrosion behaviour on the inlet and exit site of the dust system was different too as resulting from the Table 2 and the Fig. 5.

The depth of corrosion attack on the exit site of the duct system is much larger (176 µm) than on the inlet site (106 µm) what can be caused by different temperature, thickness of deposit and by precipitation of Cr carbides.

The sample of unalloyed construction steel of ASTM A519-82 (chemical composition in the Table 2) has a fine ferritic structure with small content of pearlite (Fig. 5).

After 30 days in the Al furniture the samples are damaged by general corrosion and the intensity of the one is stronger on the inlet site of the dust system (Fig. 6 B). The corrosion starts on the grain boundaries (Fig. 6 B, T). As it can be seen in the same figure the grains become larger in
the places of mechanical loading and in the thickness of 200 \( \mu m \) decarburization occurs which results in destruction of pearlite. The cast iron with globular and lamellar graphite has the smallest resistance to corrosion attack in the aggressive condition of the Al furniture. The weight losses determined after experiment are several times higher than the other tested material. By the temperature effect decarburization is visible on the both cast irons and penetrates to the depth about 100 \( \mu m \). The pearlite is changed to ferrite (Fig. 7, 8).

**Fig. 6 B** – the structure and corrosion attack after 30 days exposition of sample 3 on the inlet site and \( T \)– on the exit site of the duct system, etch. Nital.

**Fig. 7. B** – the structure and corrosion attack after 30 days exposition of sample 4 on the inlet site and \( T \)– on the exit site of the duct system, etch. Nital.

**Fig.8. B** – the structure and corrosion attack after 30 days exposition of sample 5 on the inlet site and \( T \)– on the exit site of the duct system, etch. Nital.
3. Conclusions

- All the tested materials were damaged by various intensity of corrosion on the inlet site of duct system and exit site of duct system as well. According to weight losses the best resistance reach Cr-Ni alloyed steels in condition of the duct system. It is necessary to consider the total depth of intergranular corrosion attack which damaged material (Fig. 2). According to metallography evaluation the difference between stainless austenitic steels and unalloyed steel was not very big. In this case weight losses play the role of an indicative comparison factor. Corrosion of cast irons with different shape of graphite is the most intensive in comparison with the other tested materials.

- Corrosion attack on the inlet site and on the exit site of the duct system differs in its intensity mainly for unalloyed metals. The sample from the inlet site were covered by heavy layers of deposits and corrosion products and more intensive attack can be found of all tested materials except the stainless steel stabilized by Ti (sample 2). On the exit site of the duct system the deposit thickness was thinner and the corrosion products create continual layers. This fact suggests different mechanism and kinetics of corrosion in the two localities. It is caused by different environment composition and temperature. According to the results of the experiment the bizarre corrosion behavior of the steel stabilized by Ti (sample 2) with the total depth 170 µm of corrosion damage in this locality cannot be exactly explained on the base of made experiments. Probably it is caused by the work temperature mostly in the range from 600 °C to 900 °C. It is a critical temperature of the Cr bonding phases (e.g. Cr$_2$C$_6$, δ-phase, Laves phase) what makes austenitic stainless steels very sensitive to intergranular corrosion. The Ti carbides have the typical creation temperature from 840°C to 900°C.

- Decarburization of surface layer areas is observed in unalloyed materials and it is more intensive on the exit site. Decarburization of surface layers occurs by carbon oxidation and its gradual diffusion to the surface. Oxidation during heating penetrates steel objects in a gaseous environment that contains oxygen, carbon dioxide, water vapour and heating lasts longer. Steel decarburization causes loss of mechanical properties – softens. More intensive decarburization in the exit site can be explain by faster diffusion processes under the surface of metals which are not retard by big layers of deposits.

- Grain thickening at the surface areas occurred only in unalloyed materials and especially in locations of deformation. Strain tension in this area is reduced by recrystallization at high temperature.

- The cast irons with the different graphite shape proved to be unsuitable material for the production of duct system parts considering the most intense corrosion damage and also to influence the structure in given circumstances.

- According to the results of experiments no significant difference in the intensity of corrosion attack in alloyed and unalloyed materials is observed. Stainless steel in this environment does not exhibit corrosion resistance in spite of the Cr, Ni content. Obtained results confirm that in the case of impossibility do define the work condition exactly it is needed the material selection support by experiment.

- It would be desirable to test high alloyed Cr, Ni alloys as a perspective material in these severe conditions.

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References


