METALLURGICAL AND ELECTROCHEMICAL BEHAVIOR OF S295 STEEL TUBES IN STEEL COOLING CIRCUITS

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Abstract

Corrosion damage to industrial cooling systems in steel mills is a serious problem for industry and the environment. In order to reduce this phenomenon by the subsequent development of organic-based corrosion inhibitors, a preliminary identification study of the base material and the surrounding environment of the cooling circuits is essential.

To monitor the electrochemical behavior of unalloyed steel tubes, we studied the influence of the “industrial cooling water” environment and the most influential physical parameters. This behavior of S295 grade steel will be determined by different stationary and non-stationary electrochemical methods, notably electrochemical impedance spectroscopy.

These investigations enabled us on the one hand the metallurgical knowledge of the base material, the nature of the corrosive medium, and on the other hand the evaluation of the potentials and the corrosion rates and to define the different reactions at the metal interface.

In conclusion, the tubes studied in unalloyed steel have a low resistance to corrosion under the effect of the aggressiveness of the surrounding environment (Figure 1) in this case industrial cooling water hence the need to introduce corrosion inhibitors in cooling circuits. In our case, we will focus on natural organic inhibitors that ensure an economic and environmental balance.

Keywords: Steel, corrosion, behavior, cooling water, impedance, temperature

Figure 1: Stationary and frequential electrochemical curves of the material / medium interaction

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1. Introduction:

Corrosion results from a chemical or electrochemical action of an environment on metals and alloys. The consequences are significant in various fields and in particular in industry: production stoppage, replacement of corroded parts, accidents and risks of pollution are frequent events with sometimes heavy economic impacts [1]. Since the massive use of iron alloys, it has been estimated a loss of 15% of the annual production of steel or 5 tons / second of corrosion [2]. Industrial installations exposed to corrosion damage are generally designed taking into account the composition of existing anti-corrosion products on the market. In fact, in terms of protection, corrosion inhibitors are a special means of protection against metallic corrosion [1].

Today, corrosion inhibitors are an original means of combating corrosion [3]. The originality of these inhibitors is to be the only means of intervention from the corrosive environment [4]. These are substances which, when added at low concentrations in corrosive media, reduce or even prevent the reaction of the metal with its environment [3]. Before beginning the development of corrosion inhibitors, eco-compatible and biodegradable, especially for steel cooling circuits, we have made a preliminary study on the metallurgical and electrochemical behavior of non-alloy grade steel pipes. S295 of these circuits.

2. Material and methods

2.1. Choice of material

Nuance and characterization of the material

The chemical analyzes of the seamless tube samples of the "FRX" X-Ray Fluorescence Oxygen Cooling System gave the results shown in Table 1.

<table>
<thead>
<tr>
<th>Sample code</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>V</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>TU</td>
<td>0,196</td>
<td>0,562</td>
<td>0,2239</td>
<td>0,014</td>
<td>0,003</td>
<td>0,02</td>
<td>0,041</td>
<td>0,101</td>
<td>0,173</td>
<td>0,01</td>
</tr>
</tbody>
</table>

Micro hardness tests

Micro hardness tests were carried out on samples taken from the tube. The results of Hv microhardness in different parts under a load of 5Kgf are shown in Table 2.

<table>
<thead>
<tr>
<th>Sample code</th>
<th>HV_1</th>
<th>HV_2</th>
<th>HV_3</th>
<th>HV_4</th>
<th>HV_5</th>
<th>HV_moy</th>
<th>Equivalent resistance R_M (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TU</td>
<td>139</td>
<td>143</td>
<td>137</td>
<td>151</td>
<td>129</td>
<td>143</td>
<td>480-485</td>
</tr>
</tbody>
</table>
Metallographic examinations

Optical microscopic examinations of polished sections taken from tube samples at different magnifications revealed a fine ferrito-pearlitic structure with homogeneity of grain size and shape (fig.2). The phase distribution gave 80% Ferrite and 20% Perlite with an average grain size index of about 8 (according to ASTM E1382-97, ISO643 and ASTM E112).

![Micrographs of tube samples](image)

\[ G = 50X \hspace{2cm} G = 100X \]

*Figure 2: Tube micrographs after Nital attack at 4%*

**Nuance:** On the basis of the various investigations carried out and referring to the international standards NF EN 10025 ISO 683, NF A 49-212, NF A49-213, the tube conveying cooling water from the oxygen steelworks is similar to grade S295 (equivalent to TU 48 according to the old nomenclature for seamless tubes). It is an unalloyed low carbon steel with a good compromise between mechanical properties of strength and ductility.

### 2.2. The environment

The environment in which we tested the corrosion behavior of our S295 steel is an industrial cooling water, characterized by an alkaline pH of about 9.90 and a presence of chlorides. The physico-chemical analysis of this water is presented in Table 3 below:

<table>
<thead>
<tr>
<th>Table 3: Physicochemical Parameters of Industrial Cooling Water*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
</tr>
<tr>
<td>Unity concentration</td>
</tr>
</tbody>
</table>

### 2.3- Electrochemical study and electrochemical study and test conditions

Electrochemical methods used: The evolution of the electrochemical behavior of S295 steel and the study of the material / medium interface are realized by stationary and non-stationary methods and the test conditions are as follows:
The working equipment: The electrochemical parameters were calculated using the Autolab 302N controlled by a microcomputer at the corrosion laboratory of the applied research unit in the iron and steel industry URASM / CRTI / ANNABA. Polarization resistance measurements (Rp) were performed at a scanning rate of 1 mVs⁻¹.

The measuring cell: the measuring cell used for the electrochemical tests is made of cylindrical pyrex glass with a volume of 250ml with double thermostatic walls.

Electrode References: During our experiment, three electrodes were used, a reference electrode Ag / AgCl, a platinum counter electrode and a steel grade S295 working electrode.

Working electrode: for reliable results, the working electrode must undergo a pretreatment before each test, which consists of polishing the surface of the working electrode with abrasive papers under water jet followed by drying under a flow of air. [5]

Experimental conditions According to the literature, because the behavior of materials including the tubes of industrial installations is influenced by the temperature change we play on this parameter after each change of temperature we observe our steel under optical microscope to see the degree of corrosion damage.

4. Results and Discussion

4.1. Identification of nuance:

Différentes enquêtes sont effectuées et référencées aux normes internationales NF EN 10025, ISO 683, NF A 49-212, NF A49-213, le tube conducteur de l'eau de refroidissement à oxygène s'apparente à la nuance de grade S295 (équivalent à TU 48 selon l'ancienne nomenclature des tubes sans soudure). C’est un acier à base de carbone non allié avec un bon compromis entre les propriétés de résistance et de ductilité.

4.2. Comportement to the corrosion of theier S295 in the water of circuit:

the parameters deduced from these polarization curves are summarized in Table 4. The behavior of S295 steel has a low resistance to corrosion in interaction with the surrounding medium, despite the fact that the chloride content is not high enough, therefore, with a fairly high corrosion rate, at least the electrochemical properties are not present (Table 4). In this case, the speed, the resistance to polarization are higher at 50 ° C compared to the ambient temperature. It appears that temperature fluctuations disturb the environment environment, which is the industrial cooling water.

Table 4: Parmeters of polarization curves of S295 steel in cooling water

<table>
<thead>
<tr>
<th>Paramètre</th>
<th>Ecorr</th>
<th>Icorr A/cm²</th>
<th>Corr rate mm/year</th>
<th>Polar Rate Ω</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel at 25°C</td>
<td>-0.51115V</td>
<td>1.1656E-06</td>
<td>0.013544</td>
<td>50609</td>
</tr>
<tr>
<td>Steel at à 50°C</td>
<td>-0.54139V</td>
<td>2.3583E-06</td>
<td>0.027403</td>
<td>24129</td>
</tr>
</tbody>
</table>
4.3. Electrochemical impedance spectroscopy SIE:

To study the mechanisms of corrosion and protection of metals [6]; the impedance spectroscopy method proved to be the most efficient tool. Figure 4 shows the Nyquist diagram $Z$ of S295 steel at room temperature and at 50 °C. We note from this diagram that the size of the half circle increases with the increase in temperature which reflects the increase in resistance, this phenomenon results from the protective layer.

4.4. Image of steel under optical microscope after electrochemical test at different temperatures:

We tested our S295 steel in an alkaline cooling water with chlorides of different degrees of temperature. At an ambient temperature of 25 °C, we noticed a piquartion on a part of the surface of the sample, from which we observe the structure under optical microscope "see Figure 2". Microphagy at 50 °C: At this temperature the pitting surface is larger than 25 °C. The surface condition of steel under optical microscope is shown in Figure 4.
Figure 3: Pitting of surface steel S295 at room temperature 25 °C.

Figure 4: Pitting of surface steel S295 at room temperature 50 °C.

5- Conclusion:

The various investigations carried out and referring to the international standards NF EN 10025 ISO 683, NF A 49-212, NF A49-213, the tube conveying the cooling water of the oxygen steel plant is similar to the grade S295 (equivalent to TU 48 according to the old nomenclature of seamless tubes). It is an unalloyed low carbon steel with a good compromise between mechanical properties of strength and ductility.

The results of the polarization curves of steel S295 in cooling water circuit show that the electrochemical properties in this case potential, speed, polarization resistance are higher at 50 °C compared to ambient temperature which shows that temperature fluctuations can disturb the behavior of the surrounding environment, which is industrial cooling water.

This deduction is supported by electrochemical impedance spectroscopy, which reveals that the size of the semicircle increases with increasing temperature, which reflects the increase in resistance.

Soon we will proceed to the protection of our cooling system of the corrosion phenomenon by the development and introduction of our inhibitor-based extraction of natural products which meets the economic, societal and environmental needs.
References


[5]. Abdelghani, Hemmal, Mechanical and electrochemical characterization of a welded steel joint API 5L X70 Memory of graduation ENSMM-Annab (National School of Mining and Metallurgy) 84 pages, 2016.