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INVESTIGATION OF MECHANICAL PROPERTIES AND CORROSION BEHAVIOUR FOR 1010 CARBON STEEL PIPES USED FOR STEAM BOILERS

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ABSTRACT

Depending on the conditions of their use, most equipment gets deteriorated in time. In this paper the corrosion rate (CR) was verified by using the experiment of weight loss (WL) of specimens from steam boiler pipes (SBP) made of 1010 carbon steel with a thickness of 4 mm. CR was calculated by specimens' weight loss in the corrosive environment at 25 °C in 5% NaCl - 10% H_2O_2 solution which reproduces the environment in the plant during specific times.

The mechanical properties which were verified include hardness test and tensile test. The results that have been obtained through tensile curves and hardness properties on specimens 1 and 2 were compared to a non-service specimen (3) made of 1010 carbon steel. It is concluded that there was an increase in the properties of tensile and a decrease of hardness for both specimens by comparing them with a non-service specimen. Due to overheating, a deposition of layers of lime (CaO) on the pipes was caused. It is noticed that the decrease of the mechanical properties leads to increased corrosion.

KEYWORDS: steam boilers pipes, carbon steel, corrosion rate, weight loss, hardness properties, tensile stress

1. Introduction

Over the years, the chemical engineers always provided the best information for corrosion and proper use of materials in the chemical industry and its operations.

Many scientists and researchers worked hard in this domain to answer the important question: how does corrosion occur [1].

Corrosion is a degradation of a metal by electrochemical changes that occur in the presence of the surrounding environment, which lead to the occurrence of the corrosion, namely to. a change in the mechanical properties of a metal [2, 3].

Corrosion usually begins on the stages which can be shortened by the following steps:

1. Interaction between the base metal and the corrosive environment.
2. Growth of oxidation layer and its penetration in the base metal [4].

Boiler is the heat transferring used in the production of steam (wet, toasted). We can use this steam in the power generation, heating, etc.

The main problems of corrosion that occurs in boilers are: oxidation, hydrogen damage, stress corrosion cracking, fatigue and chemical corrosion [5].

The pipes of boilers erode during the passage of water or steam inside and heated by the outside fire. Therefore, the failure can be classified into internal failure represented by the fatigue and external failure represented by oxidation, hydrogen damage, erosion and stress corrosion cracking [6, 7].

Pipe failure occurs in different parts of the boiler and the following statistics were collected: 40% in water wall tubes, 30% in super heater tubes, 15% in re - heater tubes, 10% in economizers, 5% in cyclones [8, 9].

Our aim in this research is to investigate the corrosion processes which occur in the pipes of the boiler and to study the influence of mechanical properties on corrosion.

2. Materials and methods

2.1. Specimens of experiment

Specimens for boiler tubes (horizontal and vertical boiler) were selected and numbered as follows: specimen 1 is the standard tube (non-service specimen) for the horizontal and vertical boiler (for comparison), specimen 2 is the tube that was in service for the horizontal boiler and specimen 3 is the tube that was in service for the vertical boiler, all with 4mm thickness.

The chemical composition of the 1010 carbon steel was obtained by spectral analysis device (Spectro Max) and is shown in Table 1.

2.2. Testing

Specimens with dimensions of 20 × 20 mm^2 and 4 mm in thickness were used for the weight loss measurement.

All samples have been metallographically prepared on SiC fine paper of different grit (1200 grit) followed by cleaning in distilled water, acetone and drying in hot air.

In order to evaluate the material mechanical properties, the tensile strength and yield strength have been analyzed by using a 300 KN servo hydraulic universal testing machine.

The specimens were subjected to hardness measurement, which was determined on several regions by Rockwell hardness (HRA) testing method.

3. Results and discussion

3.1. Structural characterization

Figure 1 shows the schematics of the samples used.

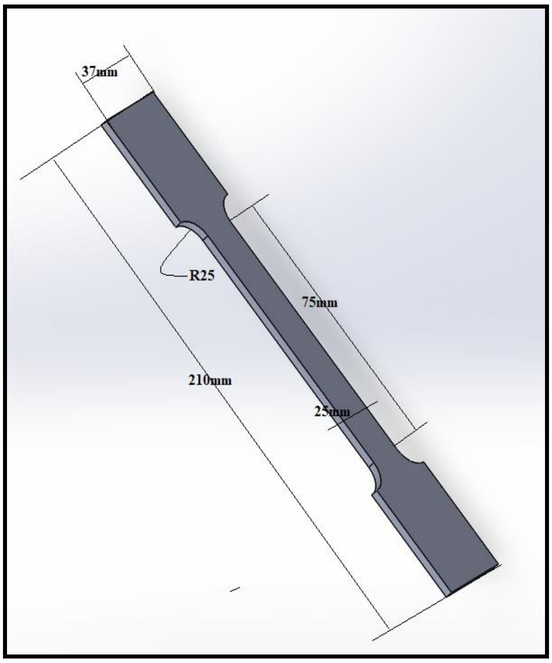

Fig. 1. *Tensile specimens used in the research*

In Figure 2 the physical tensile specimens which were used in the research are presented.

The Load - Displacement curves of the specimen are shown in Fig. 3 and the bar chart shown in Fig. 4 shows the comparison of the tensile parameters obtained from testing and the non-service specimen.

Table 1. *Chemical composition (wt. %)*

No.	C%	Si%	Mn%	P%	S%	Cr%	Ni%
1	0.094	0.076	0.004	0.01	0.404	0.088	0.09
2	0.150	0.078	0.0038	0.018	0.413	0.111	0.09
3	0.085	0.104	0.0085	0.0086	0.375	0.107	0.081

Fig. 2. *Macroscopic images of the 1010 samples used in the mechanical tests: 1) non-service specimen, 2) service horizontal boiler specimen and 3) service vertical boiler specimen*

It is noted that there is an increase in tensile properties for both specimens 2 and 3, by comparing them with specimen 1.

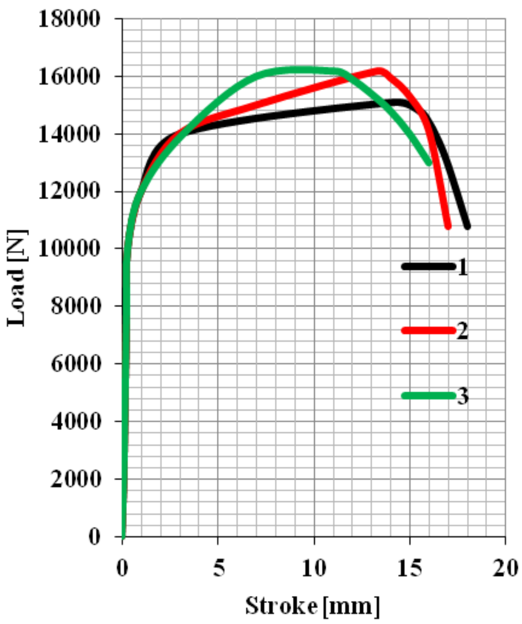

Fig. 3. *The load - displacement curves of the tested specimens: 1) non-service specimen, 2) horizontal boiler specimen and 3) vertical boiler specimen*

The hardness tests have been achieved on different regions, and they showed an approximate value of 48.6 HRA for specimen 1, 48 HRA for specimen 2 and 48.1 HRA for specimen 3.

It is noted that there is a decrease in hardness properties for both specimens 2 and 3, by comparing them with specimen 1.

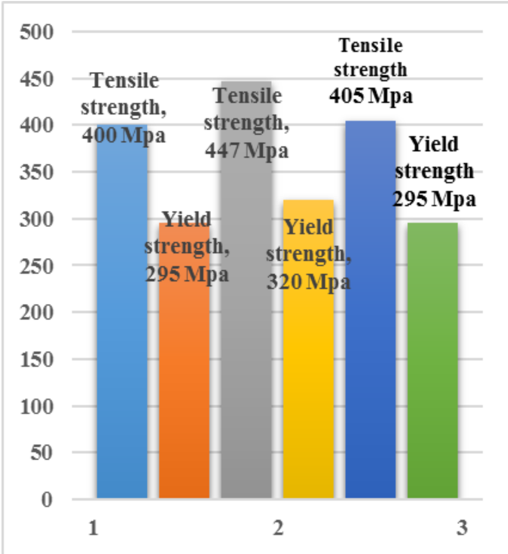

Fig. 4. *The tensile strength and yield strength of the tested specimens: 1) non-service specimen, 2) horizontal boiler specimen and 3) vertical boiler specimen*

It is noticed a decrease of mechanical properties (hardness and tensile stress) through the chart for both specimens. This makes the metal more susceptible to corrosion such as stress corrosion cracking and pitting corrosion under high temperature and high pressure. So, it is required a type of metal which has high mechanical properties to protect it from the corrosion.

In searching for the suitable metal, it is found that there is a type of carbon steel able to work in this condition.

ASTM A210 [10] is a carbon steel pressure tube with very good mechanical properties, which can be successfully used in this application.

In Table 2 are shown the chemical properties of ASTM A210 carbon steel pressure tube.

Table 2. *Chemical composition (wt. %)* [10]

ASTM	C%	Si%	Mn%	P%	S%
A210	0.27	0.1	0.93	0.048	0.058

In Table 3 are shown the mechanical properties of ASTM A210 carbon steel pressure tube.

Table 3. *Mechanical properties* [10]

ASTM	Tensile strength [Mpa]	Yield strength [Mpa]
A210	415	255

3.2. Corrosion results

The tests were carried out at 25 °C in chemical solution of 5% NaCl - 10% H_2O_2 which simulates the environment in the factory during specific times.

Using a hand grinding wheel machine, the surface of the specimens was polished. After that, surface preparations were carried out by wet grinding with a series of SiC papers to 1200 grit followed by cleaning in distilled water, with acetone and air drying.

A solution of 5% NaCl - 10% H_2O_2 in distilled water was used, to simulate the environment in the factory during specific times (every 24 h, three times) at 25 °C, whereas the concentration of solution represents the work environment.

The weight loss was monitored by measuring the initial and final mass with an analytical balance (Sartorius, model TE 153S) with a precision of 0.001 g.

We can determine the corrosion rate [11] using the following equations (1) and (2).

$$R = \frac{K \cdot W}{A \cdot T \cdot D}(mm/year) \tag{1}$$

$$W = m_i - m_f (mg) \tag{2}$$

where:

R: Corrosion rate (mm/year);
K: 87.6 (conversion constant);
W: weight loss (mg);
A: area (cm^2);
T: time (h);
D: density (g/cm^3);
m_i: initial mass;
m_f: final mass.

In Fig. 5 is presented a macroscopic image of a specimen used in the weight loss experiments.

Fig. 6 represents the variation of corrosion rate within time for all specimens, where all measurements have been repeated three times.

Fig. 5. *Macroscopic image of the tested specimen in the corrosive environment during the weight loss analysis*

It is noted that the corrosion rate increases in the first 24 hours, and it starts to decrease during the following hours (Fig. 6).

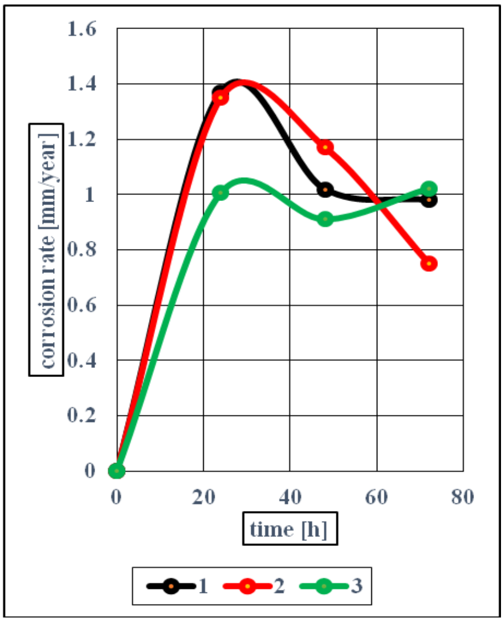

Fig. 6. *Time - corrosion rate curves of the tested specimens: 1) non-service specimen, 2) horizontal boiler specimen and 3) vertical boiler specimen*

4. Conclusion

The mechanical tests have highlighted that specimens2 and 3 present higher tensile when compared to a non-service specimen 1.

Furthermore, by making a comparison between specimens 2 and 3 and a non-service specimen 1, we notice a variation in hardness: the non-service specimen 1 has higher hardness.

The weight loss tests have indicated that the interaction which occurs in the corrosive media at room temperature leads to materials deterioration. The corrosion rate increases in the first 24 hour, and it starts to decrease during the following hours.

It is noticed that in the following hours, there is an increase in corrosion rate for both specimens 2 and 3, by comparing them with specimen 1.

This leads to the formation of a protective layer on the materials surface, inhibiting thus the corrosion process, but this leads to increasing pipe breakdown by overheating due to the low conductivity of the oxidation layer.

So, as a final conclusion it can be said that 1010 carbon steel is not a proper material for SBP fabrication and should be replaced by ASTM A210 carbon steel pressure tube that will improve its usage in this application.

By comparing A210 type and 1010 used, it is noticed an increase rate of manganese in A210 (up to 0.93%), that improves tensile properties in high temperature and pressure.

It is noticed a decrease rate of sulfide in A210 (up to 0.058%), that protects the metal from breakage in the corrosive environment.

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