Reconditioning by Welding of the Spiral Heat Exchangers Made of Austenitic Stainless Steel - X2CRNIMO17-12-2

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Abstract. The heat exchangers are playing an essential role in some widely used systems including automobiles, heating, refrigeration, air conditioning, distillation, in thermal power plants, district heating and as annexes to thermal machines. During the use of the heat exchanger, different phenomena occur due to the flow velocity of the fluids, the viscosity and the hardness of the microparticles in the fluid. The main causes of defects are corrosion and rubbing. In the presentation of heat exchanger repairs is considered a problem in terms of cost, time and efficiency. The method of repairing a spiral heat exchanger is the uncovering, which is cut outside the inside towards a sheet (s) of the exchanger when it is defective. The repair is performed by cutting the changing sheets from close to the access to the defective area. This paper presents a new method of repairing the heat exchanger, namely the intervention from the inside to the outside. The experimental plan consists of the following steps: choosing the basic material; choice of the reconditioning by welding; choice of filler material; re-welding and non-destructive examination of the samples.

1. Introduction
The heat exchangers are devices with a thermal transfer function, carrying out the heat transfer from one environment to another. They play an essential role in widely used systems including automobiles, heating, refrigeration, air conditioning, distillation (in the chemical and petrochemical industry), in thermal power plants, district heating and as annexes to thermal machines [1,2].

The fluid viscosity, flow rate and the hardness of existing microparticles during the use of the heat exchanger can lead to corrosion and cavitation phenomena. [2,3].

Currently, the repair of heat exchangers is considered a problem in terms of cost, time and efficiency. The method of repairing the spiral heat exchangers is the uncovering, that is, cutting from the outside to the inside of the sheets (spirals) of the exchanger until it reaches the defective sheet [5].

The repair is performed by cutting the sheets of the exchanger from close to close, until the access to the defective area is achieved. The steps of performing the repair are identifying the affected area; cutting the sheets from the outside to the inside to the affected area; repair by welding; the control of the repaired area; the welding of previously made cuts; the welding control of cuts and pressure testing [4,5].

Usually, most defects are located on the sheets (spirals) towards the centre of the exchanger, where the peripheral speed increases greatly, due to the smaller diameter of the turn. The starting spire has a
diameter of about 1m and the final one is 0.3m, which means a nearly 3-fold increase in the peripheral flow velocity with major implications on the cavitation phenomenon [3-5].

The method is easy to apply, but it has several disadvantages [2-5]:
- the uncovering of the good sheets, which do not have a defect, and then by the subsequent closing welding we can introduce defects in the welded joint;
- in most cases, the defects are at the spire / spirals of small diameter, so those inside. This means that we will uncover more than half of the sheets to reach the defective sheet;
- if the defects are disposed in several areas along the entire diameter of a turn and it is positioned inside the exchanger, it means that the coating is executed several times in different areas and the repair costs are very high and are not justified.

The main objective of this research is proposing a new method of reconditioning of the exchanger, namely the intervention from the inside to the outside, is removing the core and shells from the centre to the outside.

2. Methods and materials

The basic material used in the experimental plan was the X2CrNiMo17-12-2 austenitic stainless steel.

The X2CrNiMo17-12-2 austenitic stainless steel is a version of X5CrNiMo17-12-2 and is distinguished by a lower carbon content, but also by a lower yield strength and tensile strength.

In table 1 it is presented the chemical composition of X2CrNiMo17-12-2 austenitic stainless steel in accordance with the standard EN ISO 100088-3, and in table 2 the steel equivalences are presented according to other standards. The mechanical properties of X2CrNiMo17-12-2 steel are presented in table 3.

Table 1. Chemical composition of X2CrNiMo17-12-2 steel [6].

| EN ISO 10088-3 | C  | Mn | P  | S  | Si | Cr | Ni  | Mo | N  |
|----------------|----|----|----|----|----|----|-----|----|----|
| X2CrNiMo17-12-2| 0.03| 2  | 0.045| 0.03| 0.75| 16  | 18  | 10 – 14| 2 – 3| 0.10|

Table 2. X2CrNiMo17-12-2 steel equivalences.

| ASME  | DIN 17440 | EN 10088 – 3 | UNS  | AFNOR   |
|-------|-----------|--------------|------|---------|
| 316L  | 1.4404    | X2CrNiMo17-12-2 | S31603 | Z3CND17-11-02 |

Table 3. Mechanical properties of X2CrNiMo17-12-2 steel [6].

| EN ISO 10088-3 | Tensile Strength [MPa] | Yield strength [MPa] | Elongation [min, %] | Brinell [HB] | Rockwell [HRB] |
|----------------|------------------------|----------------------|---------------------|--------------|----------------|
| X2CrNiMo17-12-2 | 485                    | 170                  | 40                  | 217          | 95             |

The steps of the reconditioning by welding technology proposed are:
- The core and the first 4 shells in the centre were cut using a manual plasma cutting machine;
- Each shell was repaired by TIG welding;
- The next step was the repair of the number five shell from the inside to the outside. During the process of repairing the shell was left on the body of the exchanger;

Because the method proposed for the repair by welding of the heat exchanger is an intervention from inside to the exterior the problem with small diameter of pipes can appear.

In order to test the repair by welding process, an experimental stand was created that contains the following elements:
- video endoscopic inspection rooms;
- system for data acquisition, processing, storage and viewing camera, laptop, external hard disk, printer;
- working materials: sheet metal, pipe, protective gas, additives, wire guide tube, video signal adapters VGA - SVGA etc;
- the stand made for fixing the samples and repairing by welding;
- tools and devices necessary for processing the samples before and after welding to analyse the quality of the welded joint and the welding equipment ESAB - Origo Tig 3000i AC / DC.

The experimental stand created is presented in figure 1.

![Figure 1. Stand for repair by welding: (a) Front view; (b) Side view.](image)

The WIG welding gun used was modified in the sense that it was added to the part of the welding wire feed - roller. The welding wire comes next to the tungsten electrode through a metal guide tube. The guide tube was attached to the body of the welding gun and its neck to form a common body. The wire is exited from the tube through a contact nozzle.

Considering the welding speed, a roller at which the wire feed rate should be at least 0.8 m/min - LN 27 with two rollers was chosen.

In order to test the efficiency of the repair by welding process proposed of the heat exchangers samples were created by cutting pipes with different dimensions.

Pipes made of X2CrNiMo17-12-2 austenitic stainless steel with the dimensions 250 x 42.3 x3.2 mm and 50 x 42.3x 3.2 mm (see figure 2). In the samples were created artificial flows to imitate the cavities phenomena (see figure 3).

The cutting process of the plates was done with a manual cutting machine with cooling to avoid structural changes of the austenitic stainless steel.
All welds were executed by inserting the gun into the pipe and monitoring the molten metal bath using video-endoscopic cameras.

The parameters established were monitored throughout the welding process. Differences of maximum 5 A at the intensity of the welding current and 2 V at the arc voltage were recorded. The welding process chosen is TIG with filler material, and the protective gas is Ar 100%. The parameters of the welding regime used in the experiments were established according to the manufacturer's recommendations, and their values are shown in the table 4.
Table 4. Welding parameters.

| Parameter                  | Value     |
|----------------------------|-----------|
| Welding amperage Is [A]    | 137±5     |
| Welding arc voltage Ua [V] | 14.2±2    |
| Feed rate of welding wire va [m/min] | 1.8±1 |
| Gas flow, Ar 100%, Dg [l/min] | 13±1     |
| Welding speed vs [cm/min]  | 12-15     |

A thorium oxide tungsten electrode with a diameter of 2 mm was used. The electrodes in the thoriated tungsten contain 0.9-4.2% thorium oxide (ThO2). They offer better resistance to contamination of welds with tungsten inclusions. It is welded, preferably, in direct current. The thorium being a slightly radioactive element, when using the electrodes, through the oxide dust produced when sharpening them, a small amount of radiation is emitted.

Figure 4 shows images taken during welding on the pipes using the experimental stand made and the welding obtained are presented in figure 5.

![Image](a) ![Image](b)

**Figure 4.** Welding process: (a) before starting the welding process, (b) during the welding process.

![Image](a) ![Image](b)

**Figure 5.** Sample obtained: (a) exterior of the sample, (b) interior of the sample.

After the testing of the welding process on the samples created, the repair by welding of a heat exchanger was made, as it can be seen in figure 6.
Figure 6. The repair by welding of a spiral heat exchanger: (a) general view of the heat exchanger; (b) the cutting of the core and the first 4 shells, (c) the repair by welding.

3. Results and discussions
In order to analyse the quality of the welding points obtained on the samples and on the heat exchanger, a series of non-destructive examination methods were applied.

The visual examination applied on the samples and heat exchanger was made by direct visual testing and remote visual testing.

For the remote visual testing the following equipment was used: a videoscope VIDEOPROBE VP 300 (see figure 7) and an UV AB/LUX Check for the light intensity measurement (see figure 8).

Figure 7. The videoscope VIDEOPROBE VP 300.

Figure 8. The UV AB/LUX Check: 1- device body; 2 - sensor support; 3 - display; 4 - protection cover; 5 - white light sensor; 6 - UV sensor.

After the visual examination of the heat exchanger the following steps were performed:
- After the repair by welding non-destructive examination was applied to each shell using dry penetrant testing (see figure 9 (a) and (b));
- All the shells were introduced and re-worked, thus restoring the technological routes for cooling (see figure 9 (c));
- The edges of the shells were loaded by welding. Due to the deformations, the width of the shell changed in the sense that it was shortened by about 2 - 3 mm;
- The lathe processing of closing surfaces and installation;
- An 8-bar hydraulic pressure test was performed.

Figure 9. The control and the restoring of the heat exchanger: (a), (b) dry penetrant testing; (c) the restored heat exchanger.
4. Conclusions
Following the research study on the repair by welding of the spiral heat exchangers and the possibilities to improve the quality of the repairs resulted in the following conclusions:

- The exchangers that have defects on the first inner shell can be repaired without the uncovering process;
- The shells with larger diameters that don’t need repairs are not affected;
- Due to the fact that there is less welding on the shells the number of possible defects decreases and the value of the remaining stresses and the deformations are smaller;
- After the evaluation on the degree of wear, the shell can be repaired or replaced;
- All defects can be repaired regardless of their location on the surface of the shell;
- On shells with the thickness bigger than 6 mm, it can also be welded on the both sides of the shell;
- By performing the remote visual testing it was observed that up to a distance of approximately 100 - 150 mm from the access point, the quality of the weld is good, with no serious imperfections.

- At the dry penetrant testing small imperfections were found, like inclusions.
- During the experiments of repair by welding procedure, it was seen that as the distance from the access point is bigger the quality of the weld obtained is lower.

- Another problem is that the quality of the weld decreases with the increasing cavity size;
- At a distance of 200 mm you can see metal drops, but also burns.
- After the nondestructive examination of the samples, the following imperfections were identified: lack of penetration, improper appearance, material leaks.

5. References
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