Experimental study towards WIG welded joint. Case study: Repair by welding of X2CrNiMo17-12-2 pipes

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Abstract. Nowadays, several technological problems were raised by industrial beneficiaries regarding spiral and pipe heat exchangers repairs and thus studies were done in this regard. X2CrNiMo17-12-2, austenitic stainless steel pipes were considered for the experiments on which artificial defects, simulating functioning defects, were done. In order to perform the repair activities on the designed defects, WIG welding process was used and an experimental stand was created. This paper presents some of the difficulties that can occur during the repair by welding of pipes and the defects identified using destructive and non-destructive testing on the probes and samples created for the experimental study scope. Significant conclusions can be drawn; up to a distance of about 100 - 150 mm from the access end, the repair has a good appearance with no serious imperfections.

1. Introduction

In engineering practice, the selection of construction materials is made according to the equipment for which they are designated, and the requirements imposed in operation. Nowadays, small pipes are increasingly used both in the construction of various equipment, such as heat exchangers, and for transporting fluids [1, 2].

The following main problems must be considered when performing welding repairs on an in-service pipe [1, 2, 3]:

a. Avoiding the burning through of the pipe wall by the electric arc used as thermic source while welding;

b. Avoiding the hydrogen induced cracking, also known as cold cracking or delayed cracking, which is strongly activated by the accelerated cooling of the pipe wall in the welding area, produced by the circulation with a certain speed of the fluid under pressure in the pipe.

When designing the welding technology of the pipes under pressure must first pay attention to the use of low hydrogen electrodes and to establish correctly the conditions for carrying out the welding processes with low levels of diffusible hydrogen content in the welded joints [3, 4]. Minimizing measures must also be applied when there exists the possibility of sensitive microstructures cracking forming in the welded joint [3,4].

This paper presents some of the problems that can occur when repairing by welding of pipes, what type of imperfection can appear, and the small differences in hardness measurements.
The reason why choosing the pipes for the experimental study is in regards to the spiral heat exchangers. At the moment, spiral heat exchangers repair involves stripping, cutting from the outside to the inside of the exchanger sheets until the defective sheet is reached. The current 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 the cuts; and pressure testing. The method is easy to apply, but it has several disadvantages as the uncovering of the good sheets, which do not have a defect; the defects are at the spire/spirals of small diameter, so those inside and 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 cutting is executed several times in different areas and the repair costs are very high and not justified [8]. Performing low-access joints repair inside the pipes is similar to the spiral heat exchanger low-access repair and so, developing of new repair method for the equipment mentioned.

2. Methods and materials

The basic material used in the experimental plan was the X2CrNiMo17-12-2 austenitic stainless steel, which is a version of X5CrNiMo17-12-2 and is distinguished by a lower carbon content, but also by a lower mechanical property.

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 the mechanical properties of X2CrNiMo17-12-2 steel are presented in Table 2.

| Table 1. Chemical composition of X2CrNiMo17-12-2 stainless 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. Mechanical properties of X2CrNiMo17-12-2 stainless steel [6] |
|---------------------------------|---|---|---|---|---|
| EN ISO 10088-3                  | Tensile Strength [MPa] | Yield strength [MPa] | Elongation [min, %] | Hardness |
| X2CrNiMo17-12-2                | 485 | 170 | 40 | 217 | 95 |

The probes were repaired by welding using the WIG welding process with filler material. The filler material has the same chemical and mechanical properties as the basic material and the shielding gas was Ar 100%. The parameters of welding regime used for all the probes during the experiments were set according to the manufacturer’s recommendations, monitored during the entire welding process and their values are presented in Table 3.

| Table 3. Welding parameters |
|-----------------------------|---|
| Parameter                   | Value |
| Welding amperage $I_\text{w}$ [A] | 137±5 |
| Welding arc voltage $U_\text{w}$ [V] | 14.2±2 |
| Feed rate of welding wire $v_\text{w}$ [m/min] | 1.8±1 |
| Gas discharge, Ar 100%, $D_\text{g}$ [l/min] | 13±1 |
| Welding speed $v_\text{s}$ [cm/min] | 12-15 |
3. Results and discussions
In order to carry out the experiments, three X2CrNiMo17-12-2 austenitic stainless-steel pipes were prepared with the following dimensions: 250 mm length, 3 mm thickness and 42 mm diameter. The cutting process of the pipes was done using a manual cooling cutting machine for avoiding structural changes of the austenitic stainless steel.

In order to validate the welding repair technology, an experimental program was developed for the realization of welded seam on the areas where the artificial defect was processed (holes with the diameters of 2, 3 and 4 mm, respectively) inside pipes. The holes were drilled at different distances from the access end, respectively at 50 mm, 100 mm, 150 mm and 200 mm. The probes prepared are presented in figure 1. The experimental stand used for the repair by welding process is presented in Figure 2.

![Figure 1. Prepared probes](image1)

![Figure 2. Stand for the repair by welding process](image2)

The probes were fixed for welding in the experimental stand realized and all the welded seams were executed by inserting the welding torch into the pipe and monitoring the molten metal bath using video-endoscopic cameras. The welding source used was ESAB Origo Tig 3000i AC/DC, the welding process was displayed on the monitor during the entire repair activity and images were stored using data acquisition, storage and processing system. Figure 3 shows images taken during welding on the pipe using the experimental stand and the welding obtained are presented in figure 4.

![Figure 3. Welding process](image3)

![Figure 4. Obtained probes](image4)

After cooling, the probes were non-destructively examined using the following methods: visual testing penetrant testing and radiographic testing. The visual examination applied on the samples was made by direct visual testing and remote visual testing. For the detection of small imperfections on the
surface of the samples (which cannot be visually detected) or in the immediate proximity of the surface, the penetrant testing was used. The examination of the samples with radiographic testing was performed using X-ray radiography installation and obtaining of the image on radiographic film [4].

After the non-destructive examination, there were found several imperfections. The imperfection found in the probes are presented in table 4.

**Table 4. Imperfection found in the welded seam**

| Non-destructive method used | Code according to ISO 6520 | Imperfection name | Probes |
|-----------------------------|-----------------------------|-------------------|--------|
| Visual testing              | 506                         | overlap           | P1, P2, P3 |
|                             | 601                         | arc strike        | P1, P2, P3 |
|                             | 602                         | spatter           | P1, P2, P3 |
| Penetrant testing           | 402                         | incomplete penetration (lack of penetration) | P1, P2, P3 |
|                             | 504                         | excessive penetration | P3 |
|                             | 5062                        | root overlap      | P1, P2, P3 |
|                             | 509                         | sagging           | P1, P2, P3 |
| Radiographic testing        | 300                         | solid inclusion   | P1, P2, P3 |
|                             | 2011                        | gas pore          | P1 |
|                             | 2015                        | elongated cavity  | P2, P3 |

During the inside visual examination, it could be observed that up to a distance of about 100 - 150 mm from the access end, the weld has a good appearance with no serious imperfections but at a distance of 200 mm, metal drops can be observed and also burns.

In order to assess the welding repairs quality and eventually inner defects that cannot be identified during previous nondestructive examination, probes P1 and P2 were taken to prepare samples for the destructive tests. Eight samples were prepared using mechanical cutting under cooling fluid as follows: Probe 1 – sample 1.1, 1.2, 1.3 and 1.4 and Probe 2 – sample 2.1, 2.2, 2.3 and 2.4 (2 mm and 3 mm holes placed at different distances from the access end, at 50 mm, 100 mm, 150 mm and 200 mm respectively). The sampled area was subjected to the grinding process and polishing in order to perform the hardness tests. The tests were performed on surfaces sanded with abrasive papers (Grit 400 - 600) and polished with alpha alumina suspension with a grain size of 0.25 µm, using the Shimadzu HMV 2T Micro hardness tester see figure 5, and the hardness values are presented in table 5.

![Shimadzu HMV 2T Micro hardness tester](image.png)
Table 5. Hardness values

| Macroscopic image of the samples | Hardness values, HV0,5 | Average value, HV0,5 | Standard deviation | Coefficient of variation |
|---------------------------------|-----------------------|---------------------|--------------------|--------------------------|
| Samples 1.1 and 1.2             |                       |                     |                    |                          |
| MB 1.1                          | 177, 177, 182, 189, 186 | 182                | 5,36               | 2,94                     |
| Welded seam                     | 219, 223, 253, 236, 235 | 233                | 13,31              | 5,71                     |
| HAZ                             | 220, 208, 213, 193, 195 | 206                | 11,61              | 5,64                     |
| MB 1.2                          | 188, 192, 191, 187, 191 | 190                | 2,17               | 1,14                     |
| Welded seam- first layer        | 187, 183, 177, 172, 171 | 178                | 6,93               | 3,89                     |
| Welded seam- last layer         | 228, 216, 197, 198, 224 | 213                | 14,45              | 6,80                     |
| HAZ                             | 165, 158, 168, 175, 161 | 165                | 6,58               | 3,98                     |
| Samples 1.3 and 1.4             |                       |                     |                    |                          |
| MB 1.3                          | 183, 188, 195, 204, 209 | 196                | 10,80              | 5,52                     |
| Welded seam                     | 212, 215, 201, 196, 195 | 204                | 9,20               | 4,52                     |
| HAZ                             | 175, 172, 170, 180, 181 | 176                | 4,83               | 2,75                     |
| MB 1.4                          | 181, 183, 180, 179, 188 | 182                | 3,56               | 1,96                     |
| Welded seam                     | 185, 189, 193, 201, 194 | 192                | 5,98               | 3,11                     |
| HAZ                             | 192, 193, 191, 178, 193 | 189                | 6,43               | 3,39                     |
| MB 2.1                          | 185, 195, 193, 189, 189 | 191                | 4,34               | 2,27                     |
| Welded seam                     | 236, 237, 237, 237, 229 | 235                | 3,49               | 1,49                     |
| HAZ                             | 183, 181, 179, 170, 180 | 179                | 5,03               | 2,82                     |
| MB 2.2                          | 186, 190, 184, 190, 190 | 188                | 2,83               | 1,50                     |
| Welded seam                     | 213, 221, 239, 216, 224 | 223                | 10,11              | 4,54                     |
| HAZ                             | 177, 184, 176, 186, 180 | 181                | 4,34               | 2,40                     |
| Samples 2.1 and 2.2             |                       |                     |                    |                          |
| MB 2.3                          | 186, 184, 187, 190, 197 | 189                | 2,83               | 1,56                     |
| Welded seam                     | 237, 225, 237, 229, 231 | 232                | 5,22               | 2,25                     |
| HAZ                             | 167, 173, 176, 178, 178 | 174                | 4,62               | 2,65                     |
| MB 2.4                          | 186, 184, 187, 190, 197 | 189                | 2,83               | 1,56                     |
| Welded seam                     | 239, 230, 240, 257, 241 | 241                | 9,76               | 4,04                     |
| HAZ                             | 179, 173, 176, 186, 184 | 180                | 5,41               | 3,01                     |

The five successive measurements were performed, in line, on the characteristic areas (parent metal, welding seam and heat affected zone - HAZ) with distances of about 500µm between fingerprints, using a testing force of 4,903N applied for 10 seconds. In figures 6 ÷ 13 are presented the hardness graphs.

Figure 6. Hardness graph for sample 1.1

Figure 7. Hardness graph for sample 1.2
Analysing the presented hardness graphs, it is observed that in many of the analysed samples the hardness values in the heat affected zone are lower compared to those in the welded seam or parent metal. Although the probes are made of the same material, there are small differences between the hardness values of the parent metal used. The hardness values in the welded seams performed are higher compared to those of the parent metal, probably due to the formation of hard compounds due to the high cooling rate.

### 4. Conclusions

Tests were performed on small diameter pipe probes, on which artificial defects were created, which were subsequently repaired by welding using the WIG process. An experimental equipment was made for welding repair of the low-access areas and artificial defects on the probes were repaired using it. The obtained probes were visually and penetrant tested to highlight any imperfections positioned on the surface of the welded joint or communicating with the outside.

Based on this paper content, the following conclusions can be drawn:

- Following the welding repair procedure, it can be seen that the higher is the distance from the access end, the lower is the quality of the weld obtained.
- The quality of the weld decreases with the increase of the cavity size.
Following the direct visual testing, a series of imperfections were identified, but the most serious of these being the lack of penetration.

During the inside visual examination, it could be observed that up to a distance of about 100 - 150 mm from the access end, the weld has a good appearance with no serious imperfections.

At a distance of 200 mm, metal drops can be observed, but also burns.

Following the examination with penetrating liquids, it was observed that the outer surface of the weld has imperfections, the lack of melting being the most common.

Following the examination with penetrating radiation it can be seen that the samples showed solid inclusions.

In most of the analysed samples the hardness values in the heat affected area are lower compared to those in the welded seam or the parent metal.

There are small differences between the hardness values of the parent metals, although the samples are made of the same material (austenitic 316L stainless steel).

The hardness values of the welds are considerably higher compared to those of the parent metal, which accredits the idea that it is possible that hard phases may form in the welds during welding or after cooling.

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