Quality Analysis of Helically Welded Pipe Joints

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Abstract
This work presents quality analysis of helically welded pipe joints made by submerged arc welding (SAW). The helically welded pipes with diameter of 800mm and 11mm wall thickness have been made of L 485 MB EN 10208-2 grade with using filler OK Autrod 12.24 and two types of sintered basic flux. The quality of the welds has been evaluated by using nondestructive tests according to valid standards. Considering the experiment results it can be stated that both of used flux types are applicable for making helically welded pipes, however, the best quality of weld joints had been reached with using S A AB 1 67 AC H5 ISO 14 174 flux with granularity of 0.8 – 1.6 mm.

Keywords: Radiographic Testing (RT), Ultrasonic Testing (UT), Visual and Optical Testing (VT/OT), quality, Submerged arc welding, weld, pipeline

1. Introduction

The production of helically welded pipes intended for the transportation of natural gas is constantly rising. Currently, due to the diversification of sources and increasing consumption of natural gas, the construction of new gas pipelines is becoming more and more relevant. Due to the ever growing demands for quality of steel welded pipes, posed by customers, it is essential to seek opportunities and technical methods for production of these pipes, that allow to minimize the error rate of products, and ensure their highest degree of quality, which is the aim particularly with regard to the security of these pipelines’ service, but not least it is interesting for economic reasons. Production of helically welded pipes requires thorough optimization of the welding process. The weld joint spot tends to be critical to the lifetime of these products and the most common source of defects. Therefore, the weld joints on these pipes are inspected by non-destructive testing in 100% scale. The mechanical properties of weld joints are evaluated by mechanical tests in accordance with applicable standards for each steel grade.

2. USSK Pipe Mill production

U. S. Steel Košice, s.r.o. is producing helically SAW (Submerged arc welded) pipes on two welding lines with annual production capacity 80,000-100,000 tons per year. The helically welded steel pipes are made of low carbon as well as HSLA steel from hot rolled substrate produced by U. S. Steel Košice, s.r.o.

The pipes are delivered in accordance with ISO, EN, DIN and API standards or in accordance with agreed terms or standards.

The pipe production has a long tradition with the first helically welded pipe manufactured in 1960 as the first product produced at the plant. For almost 50 years we have supplied most European countries and the countries of the former Soviet Union. The main sectors supplied
include pipes for the transport of gas, oil and water as well as pipes for the construction markets. [8]

Each pipe undergoes a series of non-destructive tests: ultrasonic test, X-ray test, pressure test and visual inspection of surface and welds from outside and from inside the pipe. All results are recorded and archived.

The final products are shipped to the customers via truck or railway transportation directly from our storage yard. The pipes are controlled by Technical Inspection employees before shipment. We declare conformity of our products with requirements stated in the orders in accordance with EN 10 204.

Production workflow is shown in Figure 1. [8]
Table 1. Range of pipes dimension [8]

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>minimum</th>
<th>maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter [mm]</td>
<td>406</td>
<td>1422</td>
</tr>
<tr>
<td>wall thickness [mm]</td>
<td>5,0</td>
<td>12,7 (14.2*)</td>
</tr>
<tr>
<td>Standard lengths [m]</td>
<td>8,0</td>
<td>18,0</td>
</tr>
</tbody>
</table>

*subject to prior agreement

3. Material and experimental methods

For the production of helically welded pipes are used high-strength steels according to API-5 standard LS, which include steel grades X 52, X 56, X 60, X 65. In addition to these, this group also includes the microalloyed steels X 70 marked as L 485 MB grade defined in EN 10208-2, whose chemical composition and mechanical properties are declared in Table 2 and 3. [1-5]

Table 2. Mechanical properties of grade L 485 MB

<table>
<thead>
<tr>
<th>Yield strength [MPa]</th>
<th>Tensile strength [MPa]</th>
<th>Elongation [%]</th>
<th>Impact value [kJ.m$^{-2}$]</th>
<th>DWTT [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>485-605</td>
<td>min. 570</td>
<td>18</td>
<td>45</td>
<td>-20°C 100</td>
</tr>
</tbody>
</table>

Table 3. Chemical composition of grade L 485 MB (in wt. %)

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>V</th>
<th>Nb</th>
<th>Ti</th>
<th>Al</th>
<th>Cu</th>
<th>Mo</th>
<th>P</th>
<th>S</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,16</td>
<td>1,6</td>
<td>0,55</td>
<td>0,30</td>
<td>0,30</td>
<td>0,1</td>
<td>0,06</td>
<td>0,024</td>
<td>0,25</td>
<td>0,1</td>
<td>0,035</td>
<td>0,035</td>
<td>Bal.</td>
<td></td>
</tr>
</tbody>
</table>

3.1 Welding and welding parameters

The helically welded pipes of DN 800 diameter are Submerged arc welded SAW by method 121 EN ISO 4063. Preparation of weld edge is defined by STN EN ISO 9692-1. The weld edge is produced by milling. The weld joint is made as a double-sided V weld made using three welding heads positioned against each other (in position PA and PE, STN EN ISO 6947) in the device, Figure 2. Analyzed pipe had a length of 14 m.

3.2 Filler material

The filler material used for welding was welding wire OK Autrod 12.24, diameter 4 mm. The welding wire is copper coated and designed for submerged arc welding and for electro slag welding. The wire is mainly used for welding of non-alloyed structural steels of higher strength, usually up to 580 MPa, in combination with flux.

Table 4. Chemical composition of weld wire OK Autrod 12.24 /S2Mo (% less than)

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>V</th>
<th>Cu</th>
<th>Ni</th>
<th>Al</th>
<th>Sb</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,08</td>
<td>1,08</td>
<td>0,11</td>
<td>0,04</td>
<td>0,02</td>
<td>0,45</td>
<td>0,001</td>
<td>0,05</td>
<td>0,02</td>
<td>0,001</td>
<td>0,006</td>
<td>Bal.</td>
</tr>
</tbody>
</table>
For submerged arc welding of pipes were used 2 different granularities of basic agglomerated flux S A AB 1 67 AC H5 EN ISO 14 174, whose chemical composition is shown in Table 5. In welding were used fluxed with granularity from 1.6 to 0.8 mm and fine grained fluxes with granularity less than 0.8 mm to dust fraction. The flux was sorted by sieve analysis depending on diameter $\phi 1.6; \phi 1.25; \phi 1.0; \phi 0.8; \phi 0.4; \phi 0.2$ mm (Figure 3).

The flux was dried 2 hour at 300 ± 25 °C before welding. Used of flux have properties as follows: basicity index 1.6, density 1.2kg.dm$^{-3}$, suitable for AC and also DC welding current supply, hydrogen content $\leq 5$ HDM. The pipe was welded in sections, according to the scheme in Figure 4.

**Table 5. Slag analysis of flux S A AB 1 67 AC H5 (in wt. %)**

<table>
<thead>
<tr>
<th></th>
<th>Al$_2$O$_3$ + MnO</th>
<th>CaO + MgO</th>
<th>SiO$_2$ + TiO$_2$</th>
<th>CaF$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>max.</td>
<td>40</td>
<td>30</td>
<td>26</td>
<td>22</td>
</tr>
</tbody>
</table>
Figure 3 Used flux granularity (1.6 - 0.8) and (> 0.8 - dust)

Figure 4 Used flux granularity in experimental pipe production [7]

The helically submerged arc welded pipe was made using welding parameters shown in Table 6.

Table 6. Used conventional welding parameters

<table>
<thead>
<tr>
<th>Thickness of welding material [mm]</th>
<th>Welding speed [m/min]</th>
<th>Under Head No.1</th>
<th>Under Head No.2</th>
<th>Top Head</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>1.45</td>
<td>860</td>
<td>32</td>
<td>540</td>
</tr>
</tbody>
</table>

4. Weld joints’ quality evaluation methods

The visual inspection of weld joints was carried out according to EN 17637 standard. The weld joints are inspected immediately after welding and evaluated in accordance with STN EN ISO 6520-1 and STN EN 5817. The evaluation includes weld surface, size, shape and superelevation. The weld gauges and magnifying glass are used.

The experimental pipe was also evaluated using capillary method using color indication by detecting agent Diffu-Therm according to ISO 23277 (Figure 8). This method of quality inspection of weld joints is not used in mass production.

The presence of internal defects in welds was evaluated using ultrasonic flaw detection. The reflection method was used according to STN EN ISO 10893-11, the level of defect admissibility was determined by EN ISO 11666. The evaluation was done using Krautkramer
ultrasonic flaw detector with evaluation software Starmans DIO 2000. The ultrasonic inspection is focused on the identification of internal defects in the weld where the angle 4 MHz probes (Figure 5) are used, and also on the quality inspection of the material itself, where the direct 5 MHz probes (Figure 6) are used.

The ultrasonic inspection was followed by the identification of internal defects of weld joints on helically welded pipes using radiation radioscopic test according to STN EN ISO 10893-6, which is used to identify internal defects in real time. All records are stored on disk in the computer and, if necessary, they can be re-tracked. The inspection takes place on two stations. One station inspects pipe ends and the other station inspects complete helical weld along the pipe length. (Figure 7).
The quality of weld joints was also evaluated using destructive tests. The basic destructive test in the evaluation of weld joints, and basic materials used in the production of transit pipelines is the impact Charpy test. The quality of weld joints was evaluated according to STN EN ISO 9016 on a sample with V notch. The static tensile test of weld joints with transverse weld was performed according to STN EN ISO 4136 on shredder (tension testing machine). The resistance of weld joints and the place of sample destruction were evaluated. The weld microhardness was evaluated in terms of STN EN 9015-2 standard by Vickers with a load of 981.0 Nm-1. The measurements were performed on 3 metallographic sections (cuts) from each tested fraction of flux. The microhardness was evaluated in the base material, in heat affected zone and in weld metal. The macroscopic and microscopic analysis was carried out according to STN EN 1321, in accordance with the specified procedure for testing of welds according to STN EN ISO 15614-1.

5. Results and analysis

The visual inspection of the quality of weld joints did not show the presence of surface defects in weld joints, which was also confirmed by capillary test (Figure 8), which did not detect the presence of surface defects (cracks, surface pores and shrinkage) on the weld joint. The weld bead dimensions, as well as its super-elevation, evaluated by the weld gauge use (Figure 9), was consistent with the guidelines for production procedure specified for automated submerged arc welding processes. The ultrasound inspection did not record the presence of internal defects in the weld using flux with a particle size from 1.6 to 0.8 mm (Figure 10). The presence of pores was recorded with the granularity below 0.8 mm, while its frequency was within the tolerance limits for this type of product. The radiation method confirmed the results of ultrasonic inspection, where in the section welded using flux with granularity less than 0.8 mm was, recorded the presence of slag in the weld metal. The size, quantity and concentration of the welded slag are in the tolerance and the pipe as a whole can be described as being suitable and in compliance with requested quality standards.
6. Conclusion

The presented research of weld joints’ quality of helically welded pipes intended for gas transportation was carried out in order to verify the impact of welding fluxes granularity on the final quality of weld joints. While keeping the flux chemical composition, but changing the used portions of individual flux granularity declared by the manufacturer, although within the declared granularity (2.4 to 0.01 mm) towards inappropriate fine-grained, and in some cases even unusable, dust fractions, the following conclusions can be formulated based on the experiments carried out. For the production of helically welded pipes, it is appropriate to use the basic (alkaline) fluxes with granularity of 0.8 - 1.6 mm (up to 2.5 mm). The application of this granularity allows welding, in which there is no change in lengths of submerged arc, in which the solidification time of the molten weld metal is sufficient for gas exhaust and refining of molten metal from slag. The welding process can be described as a stable one. The
reduction of flux granularity below 0.8 mm, and the presence of dust fraction, leads to poor exhaust of welding fumes from the molten weld bath, and to fluctuations, even to "shooting" of electric arc and to relatively rapid solidification of the weld metal, which results in the presence of slag in the weld metal.

Due to increasing demands on the quality of welded pipes, and possible risks in the case of their damage, there is an ongoing research to eliminate these risks. The early detection of these defects in products using comprehensive non-destructive and destructive testing allows elimination of these risks, as it is presented in this article.

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