Study of how welding methods impact the stress build-up in storage tank walls

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A B S T R A C T

THE ARTICLE EXAMINES THE topical issues of vertical tank wall repair by means of welding insert plates into a temporary opening. Currently, welding of insert plates is hardly covered in public sources.

Structural elements of steel tanks are subject to wear. Most repairs involve clearing of corrosion damages and distortions of geometric shape of walls, which require repair work. Cumulative operating history of steel tanks designed for crude oil and oil products storage indicates that a more detailed study is necessary to explore engineering problems relating to repair works and development of new repair technologies.

One of the main issues encountered when manufacturing and repairing tanks are welding deformations, which reduce the strength and stiffness of metal structures, distort the size and shape of structures, and cause an overall reduction in the quality of repair works. The need to eliminate or partially reduce deformations increases the labour input required to manufacture the structure.

The most promising way of improving the quality of repair work using the insert plate method is by choosing the optimal thermal welding cycle (TWC) modes, and selecting methods of TWC parameters control depending on the geometric dimensions of the insert plate and on the welding method.

Based on analysis of the results of experimental studies, this article describes the ways to limit the impact of residual welding stresses and deformations on the geometric parameters of vertical steel tank walls during repair work by using insert plates. The analysis covers the impact of various technological factors on the parameters of the heat-induced distortion in the welding cycle. Computer modelling is proposed as a method to monitor the level of residual welding stresses and deformations.

The main conclusion of this research is the need for the development and use of computer technology to monitor the level of stresses and deformations which arise during the welding process. The scientific research results presented here are aimed at addressing the issue of improving vertical tank reliability after repair works.

Key words: welding, tank, insert plate, welds, pipelines, heat affected zone, thermal welding cycle, mechanical properties, deformation, stress

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1. Introduction

The occurrence of residual welding stresses and deformations is described in the works of many scientists and researchers. Classifications have been formed for stresses and deformations, their causes, and different methods of defining them. Methods of preventing stresses and deformations from occurring in elements during the welding process have also been investigated and described [1-16].

The process of residual stresses arising in welded elements, methods of defining residual stresses and deformations, prevention and reduction methods, as well as the use of computer technology to define stresses and deformations during welding are described in works [1-6, 17-20].

However, issues of vertical tank repair using insert plates are hardly covered in public sources.

2. The issue

The main problem in improving the quality of repair work when welding an insert plate into the temporary opening of the tank is the high level of residual welding stresses and deformations, which affects the geometric parameters of the welded elements.

Residual stresses and deformations reduce the strength characteristics of metal structures, make them difficult to assemble, distort the size and shape of structures, and deteriorate their appearance and performance.

To reduce these stresses and deformations, it is necessary to limit the heat input to metal during welding by selecting optimal thermal welding cycles. The optimal choice may depend on various factors, including welding conditions, the geometric dimensions of the welded insert plate, the welding method and technology, the metallurgic quality of the metal insert plate, the ambient air temperature, and the thermal-physical properties of the material. Therefore, the development of a separate welding task card is required for each specific repair option. This problem can be reasonably solved using computer modelling [17-20].

3. Current status

Measures taken to reduce residual stresses and deformations can be divided into three groups: those performed before welding, during welding, and after welding [21-26, 27-30].

Various methods are used to reduce or eliminate welding deformations and stresses. The principal ones are:

- preliminary and concurrent heating, which helps to reduce the degree of temperature distribution nonuniformity during welding and to reduce the metal stiffness of welded elements;
- high-temperature post-weld tempering, which reduces residual stresses by 85-90% of their initial values and simultaneously improves the plastic properties of welded joints;
- symmetrical placement of welded joints in order to mutually compensate the built-up bending moments;
- lowering heat input to the metal during welding by reducing the cross section of welded joints.

4. Technical solutions

The Pipeline Transport Institute has conducted a set of experimental studies to analyse the impact of TWC on the level of residual welding stresses and deformations, analysed sources both in Russia and abroad, considered welding practices that provide minimal deformations, and suggested a method of computer modelling.
A computer model enables to determine theoretically the rate of energy input (heat input) and corresponding residual (post-welding) deformations for each technology involved in welding tanks with different wall thicknesses (Fig.1).

The principal technical solutions came down to the development of technological approaches which provide minimal heat input to the metal during welding, and the development of a computer model which makes it possible to calculate the heat input to the metal and to assess the level of residual welding stresses and deformations.

5. Experimental studies

Experimental repair work was carried out on the metal structures of tanks. The repair work was performed using composite insert plates made of steel 09G2S (12) (Fig.2) and single insert plate with a size of 6 x 2 m (Fig.3). Welding work was performed using manual arc welding (MAW), gas metal arc welding (GMAW), and flux-cored automated welding (FCAW-S). The main welding parameters are presented in Table 1.

Various options were modelled for the repair of walls of VSTP 5000 m³, VSTP 10000 m³, VSTP 20000 m³, VSTP 30000 m³, and VSTP 50000 m³, using both 6 x 2 m insert plate and composite insert plates, as shown in Fig.1. The results of the modelling were the limit welding heat input values for MAW, GMAW and FCAW-S methods. Exceeding these limits results in distortions of the geometric shapes of tank walls (deformations) above the limit values regulated by Transneft guidelines RD-23.020.00-KTN-283-09.

The calculated values of heat input for one weld pass are presented in Table 2, which shows that the maximum values of the rate of energy input are observed in manual arc welding, and the minimum values – in solid wire automated welding. Analysis shows that the gas metal arc welding (GMAW) method is optimal for repairing tanks using the insert plate method, as it provides the lowest rate of energy input, and, as shown by additional calculations (Table 2), the lowest rate of deviation in the geometric parameters of the tank. The manual arc welding method (MAW), by contrast, shows the maximum rate of energy input and the maximum deviation in the geometric parameters of the tanks. Therefore, the use of MAW in repair using the insert plate method requires additional restrictions on heat input to the metal. Additional MAW limitations may include: smaller electrode diameter, lower welding current, reduced cross section of the weld, and welding without transverse oscillations.

6. Discussion

Analysis of previous studies has shown that the main parameter determining the level of

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1 RD-23.020.00-KTN-283-09 Rules for repairing and reconstructing oil storage tanks with volume 1000-50000 cubic m. RD-23.020.00-KTN-283-09.
Table 1. Welding process parameters

<table>
<thead>
<tr>
<th>№</th>
<th>Welding parameter</th>
<th>Weld bead</th>
<th>GMAW</th>
<th>FCAW-S</th>
<th>MAW</th>
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<tr>
<td></td>
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<td>1</td>
<td>1.7</td>
<td>3.0/3.2</td>
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<td>2</td>
<td>1.7</td>
<td>3.0/3.2</td>
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<td></td>
<td>3</td>
<td>1.7</td>
<td>3.0/3.2</td>
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<tr>
<td></td>
<td>Diameter of electrode (wire), mm</td>
<td>root</td>
<td>1.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>filler</td>
<td>1.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>facing</td>
<td>1.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Wire feed speed, cm/ min</td>
<td>root</td>
<td>from 250 to 380</td>
<td>280</td>
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<td></td>
<td></td>
<td>filler</td>
<td>from 250 to 380</td>
<td>280</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>facing</td>
<td>from 250 to 380</td>
<td>280</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Voltage, V</td>
<td>root</td>
<td>from 19 to 23</td>
<td>from 18.5 to 19.5</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td>filler</td>
<td>from 19 to 23</td>
<td>from 19 to 20</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td>facing</td>
<td>from 19 to 23</td>
<td>from 19 to 20</td>
<td>-</td>
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<tr>
<td></td>
<td>Electrode stick-out, mm</td>
<td>root</td>
<td>from 15 to 28</td>
<td>from 15 to 25</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td>filler</td>
<td>from 15 to 20</td>
<td>from 12 to 20</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>facing</td>
<td>from 10 to 12</td>
<td>from 12 to 20</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Welding current, A</td>
<td>root</td>
<td>-</td>
<td>-</td>
<td>from 80 to 90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>filler</td>
<td>-</td>
<td>-</td>
<td>from 90 to 120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>facing</td>
<td>-</td>
<td>-</td>
<td>from 90 to 120</td>
</tr>
</tbody>
</table>

residual welding stresses and deformations in the welded joint during tank repair using the insert plate method is heat input to the metal, its level and character of distribution in the repair area. The main causes of stresses and deformations in welded joints and in structures are: non-uniform heating of metal during welding, casting shrinkage, and structural and phase transformations in solidifying metal during cooling. There may also be longitudinal and transverse shrinkage of molten metal during welding, which results in the formation of longitudinal and transverse internal stresses in the weld, causing deformation of the welded joints. Deformation of products
occurs in the longitudinal direction relative to the axis of the joint due to longitudinal shrinkage, while transverse shrinkage, as a rule, causes angular deformations in the welded joint.

When developing the optimal welding technology, the most efficient method in terms of structural and process solutions is the use of the following concepts:

- two-directional X-shaped symmetrical edge bevelling for vertical joints and two-directional K-shaped symmetrical edge bevelling for horizontal joints (Figs 4 and 5);
- welding with minimal rate of energy input in the range of 0.4 to 0.9 kJ/mm;
- the use of weld beads with balanced welding sequence (one bead inside, the other symmetrically outside) (Figs 4, 5) with the aim of mutually balanced deformations. The finishing weld that creates a stiff carcass in the product should be welded the last;
- the cross-section of the weld should be minimal due to the lower angle of the edge bevelling, and shall not exceed 0.8 of the insert plate thickness;
- shape of weld beads – “thread” welds without transverse oscillations;
- backstep welding sequence (from the centre to the edges) (Figs 4 and 5);
- control of the joint cooling rate. The joint cooling rate is based on the steel grade and its strength properties, the plate thickness, the carbon equivalent and the ambient air temperature;

### Table 2. Calculated values of heat input for one weld pass in the repair of tanks with 2 x 6 m insert plate, using various welding methods

<table>
<thead>
<tr>
<th>Welding method</th>
<th>Electrode diameter, mm</th>
<th>Permissible values of heat input for tanks with various capacity, kJ/m</th>
<th>VSTP 5000 m³</th>
<th>VSTP 10000 m³</th>
<th>VSTP 20000 m³</th>
<th>VSTP 30000 m³</th>
<th>VSTP 50000 m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 GMAW</td>
<td>1.2</td>
<td></td>
<td>1900</td>
<td>1900</td>
<td>1900</td>
<td>1900</td>
<td>1900</td>
</tr>
<tr>
<td>2 MAW</td>
<td>3.0</td>
<td></td>
<td>2100</td>
<td>1930</td>
<td>2125</td>
<td>2560</td>
<td>3024</td>
</tr>
<tr>
<td>3 FCAW-S</td>
<td>1.7</td>
<td></td>
<td>2100</td>
<td>1930</td>
<td>2125</td>
<td>2400</td>
<td>2400</td>
</tr>
</tbody>
</table>

Notes:
1) * - diameter of the welding wire when using GMAW and FCAW-S methods;
2) calculations were made for the following welding rates: MAW – 5 cm/min; GMAW, FCAW-S – 12 cm/min

### Table 3. Calculated values of tank wall deviations after repair using insert plate

<table>
<thead>
<tr>
<th>Type of defect in geometric shape of tank wall</th>
<th>Minimum rate of energy input, kJ/m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Insert plate 2 x 6m</td>
</tr>
<tr>
<td></td>
<td>GMAW</td>
</tr>
<tr>
<td>1 Minimum rate of energy input</td>
<td>470</td>
</tr>
<tr>
<td>2 Deviation of top of tank wall, mm (VSTP 5000)</td>
<td>3.9</td>
</tr>
<tr>
<td>3 Deviation of top of tank wall, mm (VSTP 10000)</td>
<td>0.65</td>
</tr>
<tr>
<td>4 Deviation of top of tank wall, mm (VSTP 20000)</td>
<td>0.5</td>
</tr>
<tr>
<td>5 Deviation of top of tank wall, mm (VSTP 30000)</td>
<td>1.0</td>
</tr>
<tr>
<td>6 Deviation of top of tank wall, mm (VSTP 50000)</td>
<td>0.9</td>
</tr>
</tbody>
</table>
use of preheating to reduce the temperature difference between the base metal and the weld metal to 100 - 150°C at a distance of 250 – 600 mm from the edge of the bevel;
• free movement of the second end of the insert plate. When the width of the gap is less than 2.5 mm, the through saw cut should be made with an abrasive wheel;
• post-welding heat treatment of welded joint using high-temperature tempering at 620 - 680°C within 0.5 - 2.0 hours. Specific welding parameters are selected depending on the plate thickness and the flat rolled steel process.
• the length of each bead should not exceed 200-250 mm.
• joints should be fixed in rigid jigs.

Figure 4 shows the sequence of passes during vertical joint welding, and Fig.5 shows the sequence of passes during horizontal joint welding.

7. Conclusions

A computer model has been developed for MAW, GMAW, and FCAW-S welding methods. This makes it possible to calculate theoretically the heat input values and residual deformations. Calculated values have been established for the deviations of tank walls after repair using an insert plate, depending on heat input parameters during welding.

Rational technological methods have been proposed that enable the development of welding technologies which provide high quality of welding operations when repairing tanks using an insert plate.

Conflicts of interest

All authors have no conflicts of interest to declare.
References


