INVESTIGATION OF MECHANICAL PROPERTIES OF P92 WELDED JOINTS MADE BY MMAW

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Abstract
This article presents new results of the measurement of mechanical properties. It is focused on the evaluation of mechanical properties of P92 welded joints, welded by manual metal arc welding (MMAW). The aim of the research is influence of Post Weld Heat Treatment (PWHT) on values of hardness, tensile strength and impact energy of weld metal and heat affected zone (HAZ).

The development of modern thermal power plants is done by increasing their efficiency, which can be achieved by increasing the pressure and temperature of superheated steam to the supercritical parameters (600 °C/30 MPa). For this reason, it is necessary to develop new heat-resistant high-alloy steels. Modified 9% Cr creep resistant steel P92 has been developed for operating temperatures above 600 °C. The issue of welded joints of steel P92 is still the subject of current research.

Keywords: Steel P92, Post Weld Heat Treatment, Mechanical Properties, Welded Joints, Manual Metal Arc Welding, Heat Affected Zone, Supercritical Parameters

1. INTRODUCTION

Increasing the efficiency of power plants and improving the environment has always been the innovative driving force in the development of power plants. Economic requirements for the beneficial use of fossil fuels and the pressure on environmental protection have led to both reduction of carbon dioxide emissions and continuous improvement of the thermal efficiency of power plants. The current aim of the coal power plant is to increase the thermal efficiency from 42% to 45%, this can be achieved by increasing the steam temperature to 600 °C and a pressure to 30 MPa. [1] Therefore, it is necessary to develop new ferritic high-alloy chromium steels with improved creep resistant properties and improved oxidation resistant properties in steam at temperatures exceeding 600 °C. [2] New 9% chromium martensitic steel marked P92 was developed for these operating parameters. This steel has very high creep resistance, but as it turns out, does not have sufficient oxidation resistance at supercritical conditions of steam. Currently, the development is focused on steels that reach the desired level of creep resistance and also shows increased oxidation resistance at supercritical steam conditions [1].

2. EXPERIMENTAL RESULTS

2.1. Welding parameters

Tests were conducted at six test plates, with a thickness of 20 mm. Test joints were welded by combination of methods TIG (root layer) and manual metal arc welding with coated electrode.

Filler material Thermanit MTS 616 (EN 12070 - WZ CrMoWVNb 9 0.5 1.5) was used for welding of test joints. Chemical composition is shown in Table 1 and the minimum mechanical properties in Table 2. Parameters of welding are listed in Table 3.
Table 1: The chemical composition of the coated electrodes, wt. % [3]

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>W</th>
<th>V</th>
<th>Nb</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.11</td>
<td>0.2</td>
<td>0.6</td>
<td>8.8</td>
<td>0.5</td>
<td>0.7</td>
<td>1.6</td>
<td>0.2</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 2: Mechanical properties of coated electrodes at normal temperature after heat treatment of 760 °C/2 h [3]

<table>
<thead>
<tr>
<th>$R_e$ [MPa]</th>
<th>$R_m$ [MPa]</th>
<th>$A_s$ [%]</th>
<th>KV [J]</th>
</tr>
</thead>
<tbody>
<tr>
<td>560</td>
<td>720</td>
<td>15</td>
<td>41</td>
</tr>
</tbody>
</table>

Table 3: Parameters of welding

<table>
<thead>
<tr>
<th>Type of welded joint</th>
<th>Welding method</th>
<th>Welding position</th>
<th>Shielding gas</th>
<th>Consumables</th>
<th>Current</th>
<th>Voltage</th>
<th>Speed of welding</th>
<th>Heat input</th>
<th>Preheating</th>
<th>Interpass</th>
<th>Postheating</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>111 + 141 (root)</td>
<td>PA</td>
<td>ARCAL TIG / MIG (EG-Č 231 - 147 - 0)</td>
<td>111 - Böhler Thermit MTS 616 (EN 1599 : EZ CrMoWVNb 9 0,5 2 B 4 2H5) φ 2,5 φ 3,2</td>
<td>111: 80 - 105 A</td>
<td>111: 18 - 24 V</td>
<td>111: 2,00 - 5,50 mm.s$^{-1}$</td>
<td>111: 0,30 - 0,80 kJ.mm$^{-1}$</td>
<td>200 °C</td>
<td>max. 300 °C</td>
<td>250 °C / 2 h</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>141 - Böhler Thermit MTS 616 (EN 12070 - WZ CrMoWVNb 9 0,5 1,5) φ 2,4</td>
<td>141: 110 - 180 A</td>
<td>141: 11 - 15 V</td>
<td>141: 1,10 - 2,80 mm.s$^{-1}$</td>
<td>141: 0,40 - 1,80 kJ.mm$^{-1}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2. Destructive tests of welded joints

2.2.1. Tensile test

Transverse tensile test of welds were carried out according to EN 4136 [4], at temperature of 20° C. The minimum required value of tensile strength, according to standard EN 10216, is from 620 to 850 MPa. [5].

We assume that values of tensile strength of welded joints usually continuously decrease with increasing of dwell on annealing temperature. Our measured results show different trend, see fig. 1.
The obtained results suggest an unusual trend of tensile strength values with increasing annealing endurance. The heat treatment of 760°C/1h reached maximum yield strength of 644.5 MPa and then it is increased to 658 MPa yield strength after 2 hours. After 3 hours of annealing, the yield strength increased to the maximum (695 MPa), and then decreases.

2.2.2. Impact test

All specimens have modified dimensions 5.0 x 10.0 mm with a V notch. Specimens notches were situated in two zones of weld joints, VWT 0/2 (W-notch in the weld metal, in the axis of the weld, 2 mm below the surface) and the VHT 2/2, (H - notch in HAZ, 2 mm from the fusion line, 2 mm below the surface). All tests were performed according to standard EN 9016. [6] at +20°C.

According to standard EN 10216-2 [5] there is required impact energy in the transverse direction min. 27 J. This requirement is defined for standard size test specimens, (10x10 mm). Subject to testing in this case, there were test specimens 5x10mm. Conversion to Tab. B 3-1 in the standard EN 13480-2 [7] “Metallic industrial piping - Part 2” there is desired impact strength for specimens of size 5x10 mm 14J. The required criterion met all test specimens except specimen of weld metal without PWHT, see Fig. 2.

The results are shown in Figures 2 and 3. Fig. 2 shows a comparison of the average values of impact energy in the weld metal. Fig. 3 shows a comparison of achieved values of impact energy in the heat affected zone. These images show reduction of impact energy with dwell on the annealing temperature till 3 hours, for both weld metal and heat affected zone.
Fig. 2: Comparison of average values of impact energy in the weld metal VWT 0/2

![Average values of impact energy - VWT 0/2, PWHT 760°C](image)

This experiment confirmed that the dwell time of the annealing temperature has significant influence on the resulting impact energy. The impact energy decreases in the range of 1 to 3 hours, at 4 hours at annealing temperature impact energy reaches a local maximum and then decreases again.

3. DISCUSSION

Dependence of hardness and toughness of the weld metal related P91 steel are given in [8]. We have expected similar results in the case of welded joints of P92 steel, but they are different. The figure 4 shows the effect of PWHT on the impact energy values in the P91 steel weld joint, namely in the weld metal of electrode Thermanit Chromo 9V. Toughness during tempering at 760°C has increased regularly in the time.
interval from 2 to 8 hours [8]. In P92 steel weld metal (Thermanit MTS 616) the impact energy have achieved highest value at 760 °C/1 hour and then decreases with time of tempering till 3 hours (see Figure 2).

**Fig. 4: Influence of PWHT on impact energy of P91 weld metal**

4. **CONCLUSION**

Modified chromium steels are used for building blocks of supercritical thermal power plants because of their excellent heat resistant properties. Degradation of the properties during long-term thermal exposure is associated with changes in the microstructure of the material. The main mechanisms of material degradation are creep and high-temperature corrosion.

Based on the results we can confirm that with increasing exposure time at the annealing temperature, the tensile strength of welded joints increases till 3 hours and then decreases, so the most suitable heat treatment after welding in terms of a high tensile strength of welded joints is 760 °C/3 hours.

The dwell time of the annealing temperature has also significant influence on the resulting impact energy. The impact energy decreases in the range of 1 to 3 hours, at 4 hours at annealing temperature impact energy reaches a local maximum and then decreases again. The most suitable heat treatment after welding in terms of a high toughness of welded joints is 760 °C/1 hour.

P92 steel is weldable provided observance of the preheating temperature, interpass temperature throughout the course of welding, while complying with proper postheating and post weld heat treatment. Despite its good creep, mechanical and technological properties steel P92 has poor oxidation resistance at supercritical conditions of steam. High mass increase of corrosion products leads to overheating, degradation of local parts and flaking of oxide layers, which can cause erosion damage of the steam components surface. This fact leads to the development of new steels, which should have the requisite level of creep strength while increased oxidation resistance at supercritical steam conditions.

**ACKNOWLEDGEMENTS**

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REFERENCES


