CREEP STRENGTH DECREASE OF CAST STEEL P91 WELDMENTS

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Abstract

High-temperature martensitic steel P91, internationally marked GX12CrMoVNbN91, is the material used in the energy industry. Creep and high-temperature corrosion resistances are important properties that affect the application of this material at higher temperatures. Weldment reduces creep properties, this work deals with the quantification of this decrease in the case of material P91. The main focus is except the evaluation of creep test results given to the mathematical description of the weld creep strength reduction. Further metallographic analyses of weld joint after creep exposures were performed.

Keywords: creep, weldment, Weld Strength Factor, martensitic steel P91

1. INTRODUCTION

The core properties influencing the material application at higher temperatures include creep resistance and high-temperature corrosion resistance. In the power industry, low-alloy bainitic steels (up to 580°C), martensitic steels (up to 650°C) and for higher temperatures the austenitic steels and nickel- or cobalt-based creep resistant alloys meet the above-mentioned requirements.

We will deal with the creep resistance of the cast martensitic steel, alloyed with 9Cr, 1Mo and other elements, which is known under the designation P91. We will primarily concentrate on weld characteristics and our goal will be to describe the dependence of strength coefficient on creep exposure conditions. The weld joint represents a structural non-homogeneity in the material, or the weak point influencing resistance to damage mechanisms. This fact is more and more intensive with the increase of temperature and exposure time.

2. TESTED MATERIAL DESCRIPTION

The cast steel was produced at ŽĎAS a.s., Žďár nad Sázavou. This material, internationally designated GX12CrMoVNbN91 and supplied for testing under the heat No. 278719, must meet the requirements according to the standard C12A ASTM A217 [1] from the point of view of chemical composition and mechanical properties at room temperature. As it is obvious from the Table I, the test material meets such requirements.

For the sake of completeness of the description, we add that the basic characteristics at room temperature were tested on the material after thermal processing using the procedure 1070°C/15h/rapid cooling with air +760°C/15h/air.

The material of the heat No. 278 719 was used for fabrication of the panel, with dimensions 100x400x600 mm after machining. The panel was cut and after that welded in position PF from one side and position PC from the other side [2].

For welding in PF and PC positions, the electrodes supplied by the Böhler Company were used. The PF weld was created by means of FOX C9MV electrodes with diameters from 2.5 up to 5 mm; the PC weld was
created by means of FOX C9MVW electrodes with diameters from 3.2 up to 5 mm. The weldment was then heat treated in order to eliminate internal stress. The methods applied were ultrasonic, X-ray and magnetic methods. The above-mentioned methods demonstrated that the weld joints do not contain any undesirable defects.

The specimens for testing the welds were prepared in such manner that the heat affected zone (HAZ) was in the middle of the gauge length.

### Tab. 1 Basic material information

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
<th>Nb</th>
<th>N</th>
<th>Al</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min.</td>
<td>0.08</td>
<td>0.30</td>
<td></td>
<td>0.20</td>
<td>8.00</td>
<td>0.85</td>
<td>0.18</td>
<td>0.06</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max.</td>
<td>0.12</td>
<td>0.60</td>
<td>0.02</td>
<td>0.01</td>
<td>0.50</td>
<td>9.50</td>
<td>1.05</td>
<td>0.25</td>
<td>0.10</td>
<td>0.07</td>
<td>0.04</td>
<td>0.4</td>
</tr>
<tr>
<td>Tav. 278 719</td>
<td>0.11</td>
<td>0.52</td>
<td>0.018</td>
<td>0.002</td>
<td>0.4</td>
<td>8.95</td>
<td>0.98</td>
<td>0.21</td>
<td>0.079</td>
<td>0.0375</td>
<td>0.01</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Minimal required properties at room temperature
- $R_{p0.2} = 415$ MPa, $R_m = 585$ MPa, $A = 18\%$, $Z = 45\%$

Real properties of heat No. 278 719
- $R_{p0.2} = 509$ MPa, $R_m = 672$ MPa, $A = 20\%$, $Z = 64\%$

### 3. CREEP PROPERTIES OF BASE MATERIAL

The creep properties were tested at temperatures from 550 up to 700°C and stresses from 40 up to 240 MPa. The longest test ended by specimen rupture achieved 21,430 h. The results of our tests were first compared with the data in literature.

To this purpose, the publication of J.Halda [3] from 2005 was used, in which 9 heats tested at temperatures from 500 up to 650°C till times of rupture $10^5$ h were evaluated. The creep resistance of has been evaluated using the Larson-Miller method:

$$\log \sigma = A_1 + A_2 P_{LM} + A_3 P_{LM}^2$$

where

- $P_{LM} = T(\log t + A_4)$, $\sigma$ is stress (MPa), $T$ is temperature (K), $t$ is time to rupture (h) and $A_1$, $A_2$, $A_3$, $A_4$ are material constants.

For the evaluation, the constant $A_4 = 30$ was applied, which occurs in literature in case of the steel P91 the most frequently. The creep resistance evaluated as above-described is plotted in Figure 1 in a solid line. Besides, the stress scatter limits ±20% are shown. Our results are symbolized in this figure by points. It is obvious that our values range near the course of mean values of the literary curve. In no case were they occurring beyond the ±20% limit. Thus we can state that the heat No. 278 719 monitored by us shows a creep resistance fully comparable with literary data.

Then, the base material creep properties were evaluated by means of the relation (1), and the following values were determined:

- $A_1 = 2.18408761E-01$
- $A_2 = 2.51646647E-04$

![Fig. 1 Comparison of own results and literature data](image1.png)

![Fig. 2 Creep strength of P91 base material](image2.png)
Stress dependence on test temperature and achieved times to rupture is depicted in Figure 2. Moreover, this figure also shows the areas of the curve in which we will occur unless the temperature exceeds 625°C and the service life 2x10^5 h. Good pertinence of the experimental results to the service life curve is obvious.

4. INFLUENCE OF THE WELD JOINT ON CREEP RESISTANCE

4.1 Weld Joint CREEP Resistance

The creep properties of the weld joint created by both technologies PC and PF were monitored again at temperatures ranging from 550 up to 700°C and stress from 45 up to 230 MPa. During the longest test more than 23,000 hours have been achieved so far. The results of experiments have again been evaluated by means of the equation (1). The following values of coefficients were determined:

\[ A_1 = 4.40245592 \times 10^0 \quad A_2 = -3.26402746 \times 10^{-5} \]
\[ A_3 = -1.63930529 \times 10^{-9} \quad A_4 = 30 \]

The weld joint creep resistance is compared with the base material (where the experiment results are no longer marked) in Figure 3. It is obvious that the character of both curves is identical at lower temperatures and stresses. However, at the approximate value of \( P_{LM} = 27,000 \), characterizing higher test parameters, the curve of weld joints is beginning to decline compared to the basic material. The differences between the results of PC and PF technologies were not obvious and therefore we will assess them as the only set of data.

4.2 Mathematical Description of Weld Strength Reduction

Reducing the weld joint creep resistance with the period and temperature of exposure can be expressed by strength coefficient that represents the relation of creep resistance properties of weld joint and basic material. To this purpose, the below-mentioned relation is applied [4]:

\[ WSF(t) = \frac{R_{w}(w)/t/T}{R_{b}(w)/t/T}, \quad (2) \]

Where: \( WSF(t) \) is a reduction coefficient of the weld joint strength,
\( R_{w}(w)/t/T \) is creep rupture strength of weld joint at temperature \( T \) and time to rupture \( t \),
\( R_{b}(w)/t/T \) is creep rupture strength of basic material at temperature \( T \) and time rupture \( t \).

In order to express \( WSF \) we have applied the mathematical description which was applied earlier [5-7]. The description is as follows:

\[ WSF(t) = 1 - S_1 \exp \left( S_2 \ln t + S_3 \right) \]

\[ (3) \]

Where: \( S_1 = s_{11} + s_{12} T + s_{13} T^2 \), \( \ln S_2 = s_{21} \exp(s_{22}.T) \), \( S_3 = s_{31} \exp(s_{32}.T) \),
\( T \) is temperature (K), \( t \) is time to rupture (h), \( s_{11}, s_{12}, s_{13}, s_{21}, s_{22}, s_{31}, s_{32} \) are material constants.

The time and temperature course of \( WSF \) is for the cast steel P91 with the weld illustrated according to the model (3) in Figure 4.
5. ANALYSIS OF FRACTURES

Specimens with weld after creep exposure 550°C/230MPa/105,25h (YT 98), 600°C/140MPa/601h (YT 75), 650°C/60MPa/1460,25h (YT 77) and 700°C/45MPa/1275h (YT 102) (see Figure 5) were chosen for fracture study. Samples were after application of usual methods of grinding and polishing, etched with the chemical agent Vilella – Bain. For sample after creep exposure 550°C/230MPa/105h, the rupture was in the base material. The case of samples after exposures 600°C/140MPa/601h and 650°C/60MPa/1460h is a different situation. Here, the weld joint already influences both the creep service life. The ruptures are located in the intercritical area on the boundary of the base material and HAZ. Fracture in HAZ of specimen after creep exposure 600°C/140MPa/601h is demonstrated in Figure 6. They are examples of typical fractures that can be anticipated in technically important cases. The rupture of the sample after exposure 700°C/45MPa/1275h occurred in the weld. However, this creep exposure is already beyond the technical interest.

Fig. 4 Creep strength decrease of P91 steel weldment

Fig. 5 Specimens chosen for fracture analyses
6. CONCLUSION

The objective of the work submitted was to test the weld joint creep resistance decrease in comparison with the base material of cast steel P91. This activity resulted in the following knowledge:

a) Decrease of creep resistance with the time and temperature of exposure for the weld joint is faster than for the basic material. This difference is apparent from Figure 2.

b) Strength reduction of the WSF weld can be described mathematically. Figure 3 shows dependence of WSF on the time to rupture at different temperatures.

c) At short exposures the creep rupture is either in the basic material or out of the weld joint. In case of technically important exposures, however, the weak point of the structure is the area between HAZ and the basic material.

ACKNOWLEDGEMENTS

This work was supported by Ministry of Industry and Trade project No. FR/TI1/257.

REFERENCES


