NUMERICAL ANALYSIS OF THERMAL STRESSES IN WELDED JOINT MADE OF STEELS X20 AND X22

by

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Stress calculation of steam pipeline is presented, focused on the welded joint. Numerical calculation was performed using the finite element method to obtain stress distribution in the welded joint made while replacing the valve chamber. Dissimilar materials were used, namely steel 10CrMoV9-10 according to EN 10216-2 for the valve chamber, the rest of steam pipeline was steel X20, whereas the transition piece material was steel X22. Residual stresses were calculated, in addition to design stresses, indicating critical regions and necessity for post-weld heat treatment.

Key words: *valve chamber, welded joint, strength calculation, heat treatment*

Introduction

In the part of steam pipeline made of high-alloyed martensitic steel X20CrMoV12-2 substitution of valve chamber has been made in order to increase capacity of power plant, i.e.to increase parameters of steam (pressure and temperature). Because of the long exploitation there was a decrease in hardness due to degradation the old steam pipeline. Part of new chamber to be welded with the old part, was also high-alloyed martensitic steel X22CrMoV12-1. It was necessary to connect steam pipeline of low thickness with piece made of different material with higher thickness, meaning that transition piece should be made in order to avoid stress concentration. If the transition piece would be made of the lower strength material (in this case X20), it would be undersized. Therefore, transition piece should be made of higher strength material in the joint. Figure 1 shows design for the transition piece and surrounding steam pipeline, including transition piece.

Dimensioning and calculation of welded joint

For dimensioning of welded joint and calculation of its strength standard EN 10216-2 will be applied, and for calculation of allowed stress TRD standards series 300 will be used. Following parameters have been known: pr=18.3 MPa, pc=19.6 MPa, tc=545 0C.For steel

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X20 the allowed stress σ_{doz} will be calculated using: the safety factor S=1.5, the time strength for 100000h and, and the validity factor of the welded joint, in this case equal to 1, :

$$\sigma_{doz} = \frac{R_{p0,2\vartheta} \cdot \xi}{S} = \frac{128 \cdot 1}{1,5} = 85,33\,\text{MPa} \tag{1}$$

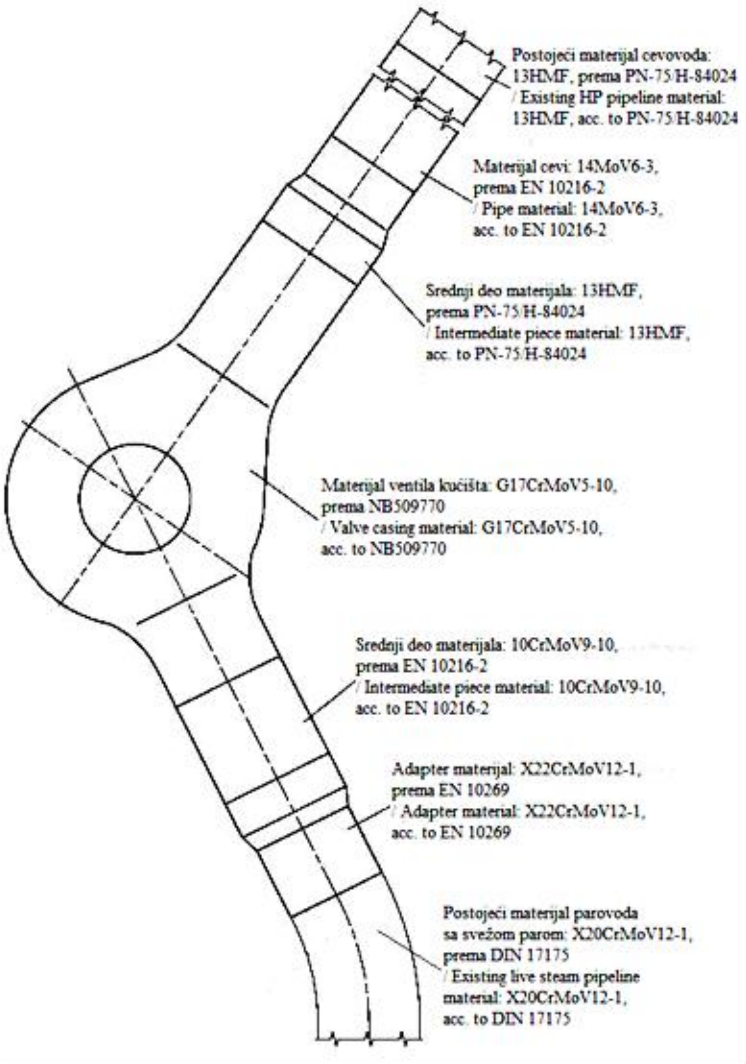

Figure 1. Design of valve chamber.

The minimum wall thickness is obtained from the equation:

$$\frac{p \cdot d_u}{2,3 \cdot s} \le \sigma_{doz} \Rightarrow s \ge \frac{p \cdot d_u}{2,3 \cdot \sigma_{doz}} \tag{2}$$

where: working pressure $p = p_r = 18,3 MPa$, d_u – inner diameter of the welded joint:

$$s \geq \frac{18,3 \cdot 0,258}{2,3 \cdot 85,33} \Rightarrow s \geq 0,024\,\text{m} = 24\,\text{mm} \tag{3}$$

To adopt the first higher standards values for outer diameter, [1-4], one should calculate:

$$d_s = d_u + 2s = 258 + 2 \cdot 24 = 306\,\text{mm} \tag{4}$$

The first higher value outer diameter according to standard is $d_s = 324\,\text{mm}$, so the adopted value for thickness of welded joint is:

$$324 = 258 + 2 \cdot s \Rightarrow s = \frac{324 - 258}{2} = 33\,\text{mm} \tag{5}$$

Working stresses in place of welded joint

The parameters used to calculate working stress are: d_u = 258 mm, p_c= 19.6 MPa, s = 33 mm. For thin-wall elements formula for calculation of stresses in pipe loaded by inner pressure is [1-4]:

$$\sigma_i = \frac{p \cdot d_u}{2,3 \cdot s} \tag{6}$$

$$\sigma_i = \frac{19,6 \cdot 258}{2,3 \cdot 33} = 66,62\,\text{MPa} \tag{7}$$

The obtained value for stresses will be compared with value of numerical calculation using the finite element method and software Abaqus.

Modelling of the welded joint and the numerical calculation of stresses

For welded joint modelling in Abaqus, ¼ of pipe cross-section is used, because it is axi-symmetric with X and Y coordinates, as shown in Figure 2.

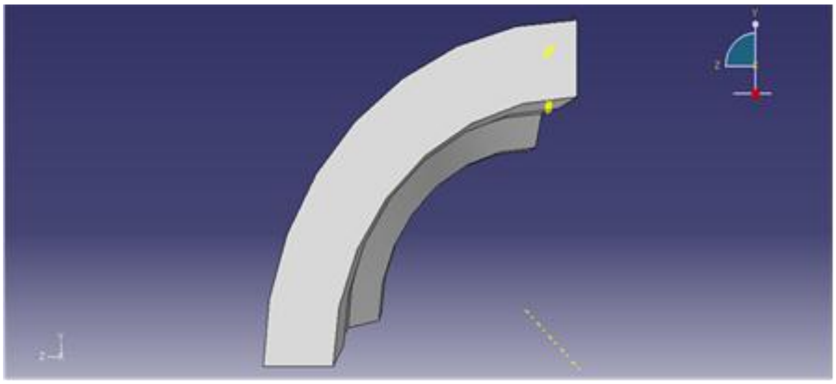

Figure 2. ¼ cross-section pipe

Figure 3 shows a section of pipe where one can see welded joint of two steels with prominent HAZ. Figure 4 shows the finite element mesh.

The boundary conditions applied for this model is fixed nodes on all four sides to get reliable results stresses the central part. The boundary conditions are shown in Figure 5.

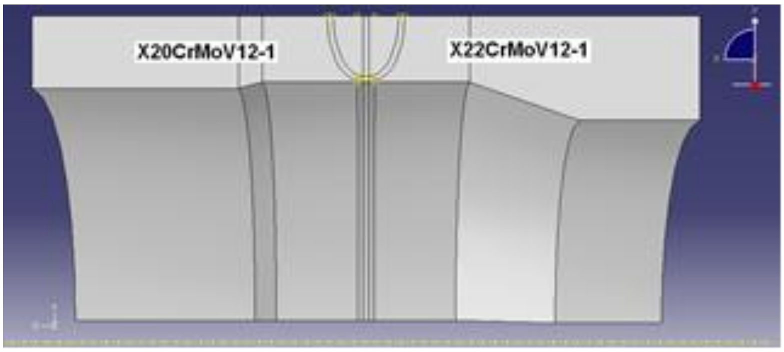

Figure 3. Welded joint two steel with HAZ

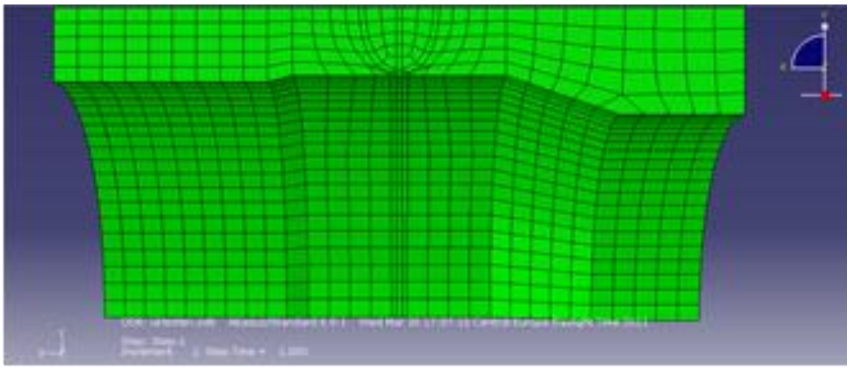

Figure 4. The finite element mesh

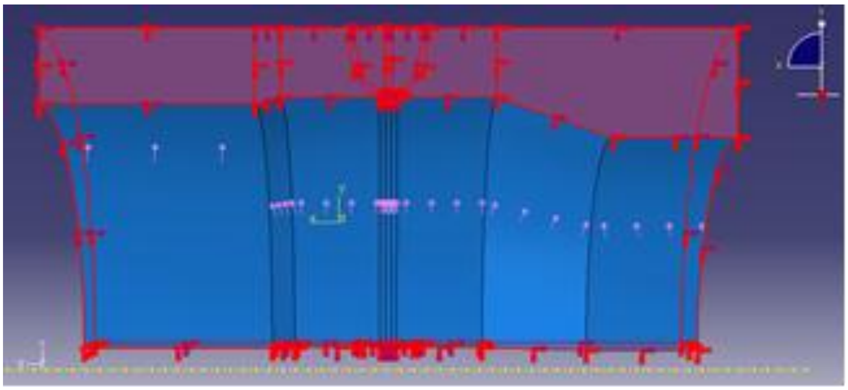

Figure 5. Boundary conditions

With given boundary conditions (Figure 5), and corresponding material properties (Elastic modulus and Poisson ratio), Von Mises equivalent stress for the internal pressure has been calculated, providing results very close to the value obtained by formula (7), as shown in Figure 6.

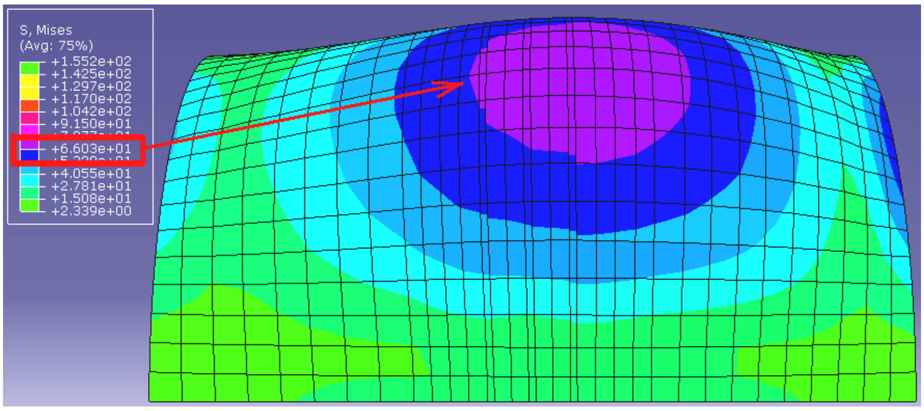

Figure 6. Von Mises stress in the pipe center due to the pressure load

It is generally known that highest stresses due to mechanical loads appear at the outer surface, as obtained in this case. Stresses on the inner surface are negligible in this case and their value is about 3 MPa.

Value of residual stress in welded joint without subsequent heat treatment

When welding martensitic steel, experience shows that the subsequent heat treatment is inevitable, and its importance is crucial. To prove this, the residual stresses were calculated using the finite element method, applying procedure described in [4-5] and software ABAQUS, The paper shows the value of stress if welded joint has not been heat treated. Figure 7 shows the stresses at the outer surface of the weld metal, and Figure 8 stresses at the inner surface in the root pass and HAZ.

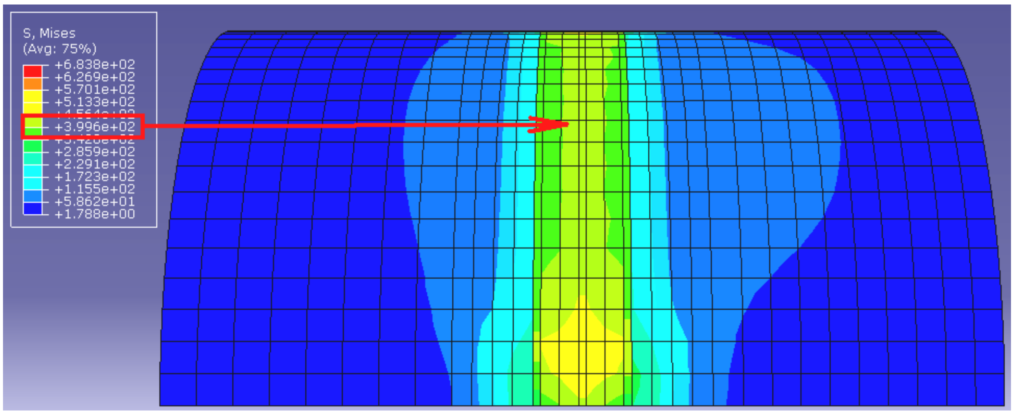

Figure 7. Stresses in outer surface weld metal due to cooling and action pressure loaded in pipe

Knowing that the yield strength of steel X20 is cca 500 MPa, and for steel X22 cca 600 MPa, stresses shown in Fig. 7-8 are unacceptable for these materials, because it maximum value is 683.8 MPa.

Figure 8 shows the stresses in the HAZ significantly exceed the yield strength steels to be welded. The highest residual stresses are in the HAZ because very small volume of material expands during cooling of the weld metal.

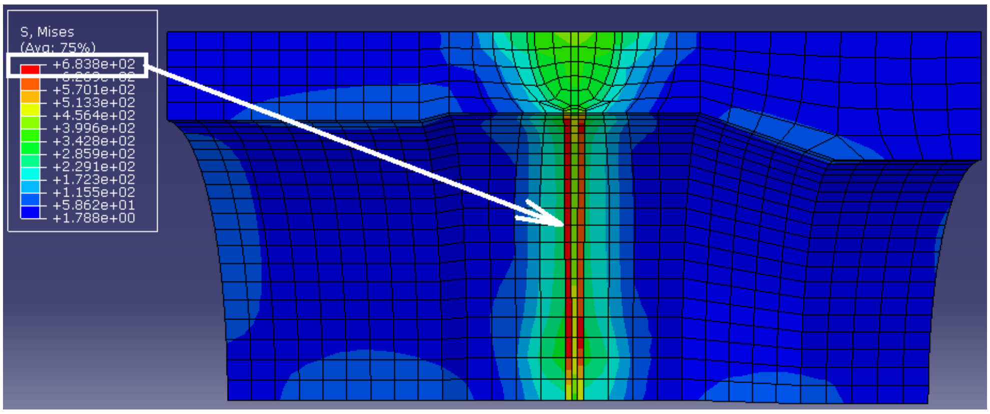

Figure 8. Residual stresses after welding in HAZ

Conclusion

Components in power plants operate at high temperatures, being exposed to the complex stress state, consisting of mechanical and thermal stresses, including residual stresses due to welding. Therefore it is of crucial importance to performed precise stress calculations, including residual stresses if the heat treatment has not been performed after welding. As shown in this paper, stress calculation, performed by the finite element method, indicated that the residual stresses overcome material yield strength, leading to the conclusion that heat treatment after welding is inevitable in this case.

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