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Crack growth resistance of weldment constituents

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Abstract

The overmatching can affect the occurrence of cold cracks after welding in high-strength low-alloyed steels of 770 MPa yield strength class. The welding consumable has been designed in a way to produce WM with slightly lower strength properties compared to BM (undermatching effect). The application of high-strength low-alloyed steel SUMITEN 80P, required a large scope of testing for estimation of behavior of welded joints under different loading conditions, in order to give the reliable estimation of penstock safety.

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Keywords: triaxiality; Crack; HAZ; welded joint.

1. Introduction

As it is known, cracks in welded joint cannot be excluded, but the influence of crack growth should be analyzed when considering construction safety. In assessing the load of the structure with a crack, the data about the crack behavior in its spread through the material structure, and through its welded joint are needed, Omar et al. (2004). Contemporary structural steels have improved mechanical properties compared to conventional steel, which is achieved by the usage of new findings in the field of steel production (the grain refinement, micro alloying, thermo mechanical processing). Today welded constructions are successfully made of steel with yield strength of 700 MPa or more. The usage of steel with high strength for welded structures is a result of satisfactory solutions to problems that occur in their welding, Burdekin and Stone (1966).

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The main goal in this research is the experimental crack growth analysis for certain welded joint constituents of complex high strength alloyed steels, concerning both the specimens and real structures, as well as the influence of crack growth on the safety of the welded joint. In order to perform the welding of such structural steels, the welding filler material is designed to obtain a somewhat lower value of the weld metal strength than the strength of the parent metal (PM) (undermatching effect), Dzindo (2018).

2. Experimental program

This paper deals with numerical simulation of the tube during the bending in three points, using software package ABAQUS. Three models are made: the first represented the tube made of basic material (BM), while the other two models contained welded joints. The second model is made with the crack and the notches in the middle of welded joint, while the third model contains the notch (as well as the crack) that is moved closer to the HAZ. The initial crack length of 2.3 mm is adopted for all three models. A set of tubes and dimensions correspond to the dimensions previously used in the experiment. All models were made as 2D. Mechanical properties for the elastic and plastic behaviour in the numerical simulations are taken from the literature and presented in Table 1, for the base material and weld metal. Based on the values of yield strength for both materials, it can be seen that it was obvious undermatching. It should be noted that the lowest values from the literature were adopted, Dzindo (2018).

Table 1. Steel SUMITEN 80

Material	Yield strength (MPa)	Tensile strength (MPa)	Break elongation (%)	Elasticity module (MPa)	Poisson's coefficient (-)
SUMITEN 80P	770	806	22	206000	0.3
M38 US 80B	585	771	21.5	210000	0.3

Figures 1-3 show the stress distribution, plastic deformation and displacement in models made of BM, with symmetrical and asymmetrical welded joint. All the results are shown for the deformed shape of the tube for bending in three points, Dzindo (2018). As it can be seen from these figures, the plastic deformation and stresses reached the highest value at a work load, as well as at the crack tip, which was expected, Dzindo (2018).

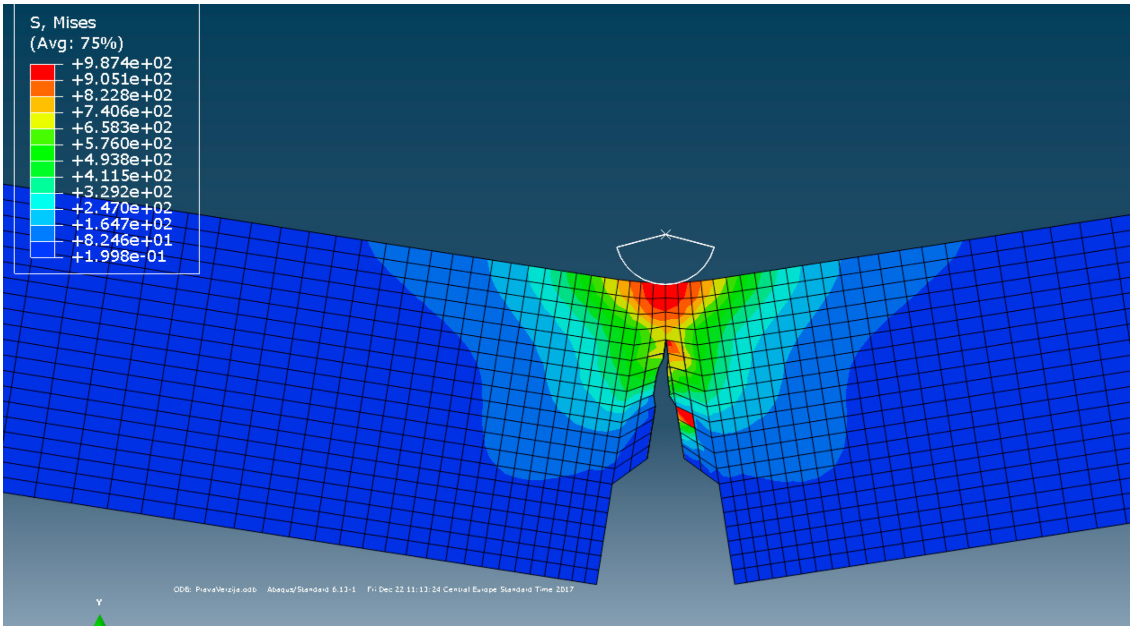

Fig. 1 Stress distribution in the model made of BM

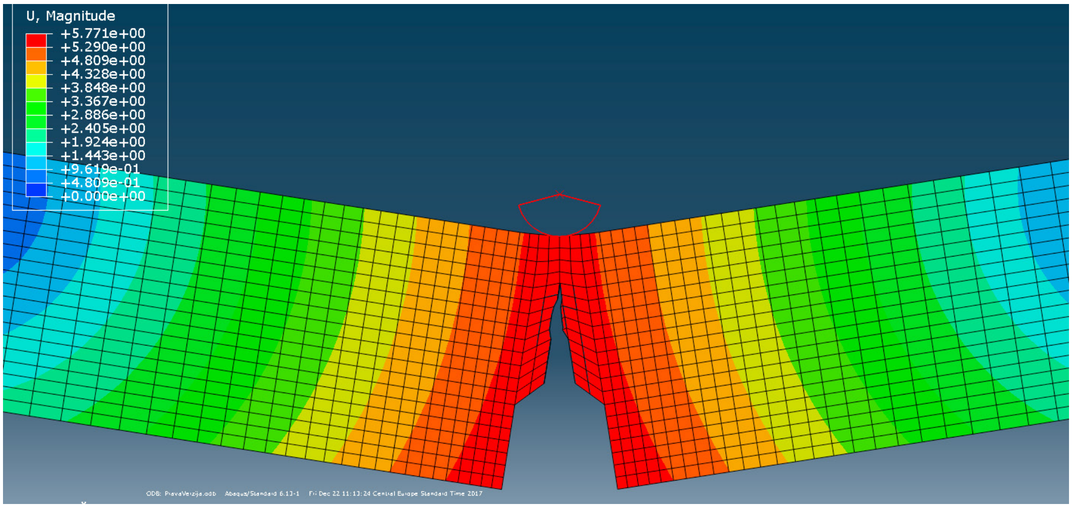

Fig. 2. Displacements in the model made of BM

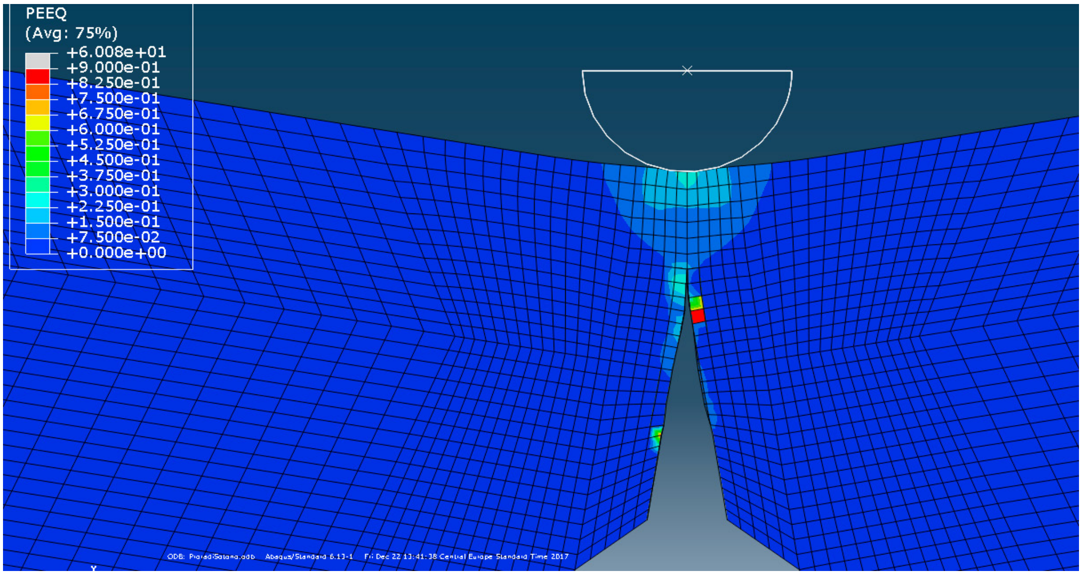

Fig. 3 Plastic deformations in the model with symmetrical welded joint

The maximum displacement (the deflection) in the case of the tubes made of base material is 5.771 mm that is very close to the experimentally measured 5.5 mm (the difference is about 5%). It should be noted as well that the current strain of numerical model fits the diagram force-displacement for OM to a great extent- in the beginning, the tube slowly bents until the moment when the displacement reaches a value of about 1 mm (which corresponds to the displacement on the diagram when the maximum force or tensile strength is reached). After reaching this value, the tube begins to deform significantly faster, due to the loss of capacity and crack growth (the length of crack has doubled in comparison to the initial value), Dzindo (2018).

In the case of the tube with the welded joint and notch /crack in the middle, the distribution of stress and strain is the same as in the first case, considering the stress concentration and maximum value of plastic deformation.

The stress concentration is expressed in the model made of BM in the greatest extent, where it reaches a value of 938 MPa at the crack tip and at the point of load. The lowest values are in the model with an asymmetric joint due to the relative position of point/crack initiation and the spot of force acting (860.5 MPa). The largest crack growth was noted in the model with a symmetric joint, while the smallest is detected in the case of test tubes made of BM, which could be expected, since it is an undermatching welded joint. For models with the notch/crack, stress and plastic deformation are the biggest near the point where the force acts and/or in the crack tip. In this case the movement is significantly small (4.457 mm numerically and 4.0 mm experimentally), that was expected, since the crack is moved in relation to the direction of force action. That means that force acts on the "stronger" cross-section. It can also be seen that in this case the crack is progressing at a certain angle (in the first two cases growth took place in the direction of the Y axis), Dzindo (2018).

3. Conclusion

For models with the notch/crack, stress and plastic deformation are the biggest near the point where the force acts and/or in the crack tip. In this case the movement is significantly small (4.457 mm numerically and 4.0 mm experimentally), that was expected, since the crack is moved in relation to the direction of force action. That means that force acts on the "stronger" cross-section. It can also be seen that in this case the crack is progressing at a certain angle (in the first two cases growth took place in the direction of the Y axis).

Based on the result shown in this paper, it can be concluded that numerical analysis has presented, with sufficient precision, behavior of tubes tested on bending in three points, for three different models (different materials-model BM) and position of the notch and cracks in weld metal (symmetrical and asymmetrical models). The contribution of this simulation is the possibility to develop a model that would prevail the real behavior of tubes in quick and relatively easy way, considering the stress concentration and deformation during the experiment.

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