MODELING CONDITIONS SUITABLE FOR INITIATION OF STRESS CORROSION CRACKING IN THE HEAT AFFECTED ZONE OF THE CROSS WELD OF AUSTENITIC STEEL PIPES

MAREŠ Vratislav[1], BYSTRIANSKÝ Jaroslav[2], KRAUS Martin[1]

[1]Center of Advanced Innovation Technologies - VSB - Technical University of Ostrava, Czech Republic, EU
vratislav.maresl@vsb.cz
[2]University of chemistry and technology Prague Department of Metals and Corrosion Engineering, Prague, Czech republic, EU

Abstract

Steels in the cooling water circuits are most vulnerable to localized corrosion, crevice corrosion or deposit corrosion, intergranular corrosion. Austenitic steels excel in their resistance to corrosive environments. In case of use of the tubes in the cooling circuits is necessary to connect them by welding. Welding of austenitic steel is not the easy process in the field of welding. Place of weld joint then becomes a critical place for mechanical properties, but also for corrosion resistance. For application of invoking of stress corrosion cracking have been selected tubular bodies of the most commonly used steels EN 1.4541 and 1.4571. On these transverse welded tubes were manufactured artificial defects by (EDM) method. For the tests were used modified welds with artificial defect and without it. These defects were intended to localize of future damage. The thus prepared samples were exposed in corrosive environments. To induce stress corrosion cracking for tubular bodies from austenitic steels was used method of exposure in the melt $MgCl_2.6H_2O$ [1]. It is known that method for austenitic high alloy steels, is very sensitive to the presence of local areas and under the influence of tensile stress (and residual stress). Modeling of conditions for crack initiation corrosive damage help to determine how the weld joint behaves in aggressive environment exposure. These knowledges help to prevent accidents. Of course is possible take into account the resulting knowledge in the design and life prediction of cooling water circuits.

Keywords: Stress corrosion cracking, austenitic steel, the corrosive environment, weld joint, heat-affected zone

1. INTRODUCTION

The aim of this paper is to describe the possibility of simulating corrosion cracking in the heat-affected cross-welding zone of stainless steel tubular bodies. The austenitic stainless steel grade of EN 1.4541 and EN 1.4571 is a material widely used in industry for its environmental resistance. Due to the need to bond this material to the welding process, there is an area with reduced corrosion resistance. The formation of this concentrator and the effect of corrosive environments can cause cracks and final break. The heat-affected zone plays a major role, which has reduced corrosion resistance resulting from local chromium depletion of the steel and a relatively high level of residual stresses. The existence of continuous active pathways in steel and the presence of tension provoke cracking [2, 3].

The research in this article focuses on the assessment of the state of corrosion-resistant stainless steel tubes after exposure to corrosion environment. The simulation of corrosion exposure and subsequent defects analysis has a great practical benefit in industrial use. The outputs can help optimize the welding process of stainless steels and "production" of natural defects for testing non-destructive methods of detecting steel surface defects.

2. MATERIAL AND AND EXPERIMENTAL METHODS

For the analysis were used tubular bodies of steels EN 1.4541 and EN 1.4571 with transverse weld. Longitudinal cuts of pipes are shown in **Figure 1**. Specimen numbers 2, 7, 14 and 18 identified the individual tubular bodies. **Table 1** shows the basic dimensions of the tubes and the dimensions of artificially created defects. Artificial defects were created by electrical discharge machining.

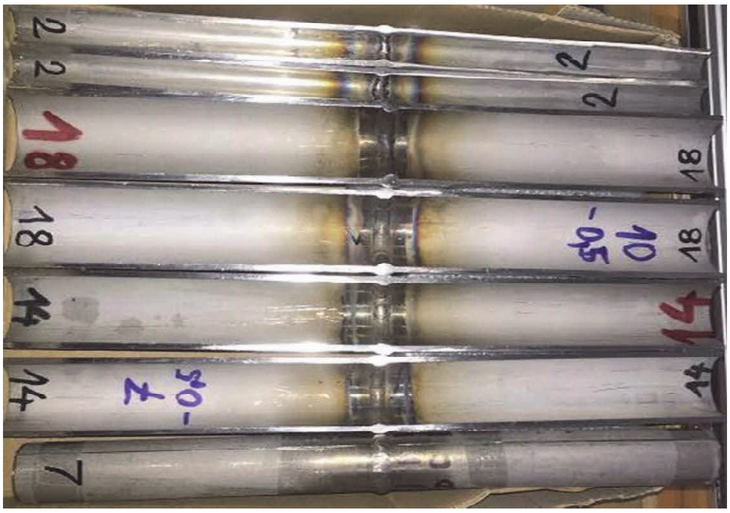

Figure 1 Tubular bodies after longitudinal cutting

Table 1 Tubular bodies for modeling the initiation of corrosion defects

Designation	Pipe dimension [mm]	Artificial defect dimension [mm]	
		Depth	Length
2	18.0	0.5	3.0
7	26.8	0.5	3.0
14	33.7	0.5	7.0
18	38.0	0.5	10.0

For specimens 2, 7, 14, 18 were performed complete analysis of chemical composition of pipes and local analysis of basic material and weld metal. The analysis verified that the tubular bodies were made from stabilized steels corresponding to the quality of EN 1.4541 (No. 2 and 7) and EN 1.4571 (No. 14, 18). The chemical composition is shown below in **Table 2**.

Table 2 Chemical composition

Specimen	**Element wt. %**														
	C	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**	**Mo**	**Al**	**Cu**	**Co**	**Ti**	**Nb**	**V**	**W**
2	0.049	0.54	1.37	0.041	0.015	18.1	9.2	0.16	0.037	0.25	0.18	0.33	<0.004	0.12	0.011
7	0.053	0.45	0.71	0.042	0.017	17.7	9.42	0.13	0.048	0.17	0.19	0.36	<0.004	0.085	0.012
14	0.081	0.31	0.94	0.051	0.018	17.3	11	2.1	0.041	0.27	0.29	0.34	0.044	0.086	0.059
18	0.069	0.41	1.2	0.051	0.016	17.3	10.9	2	0.083	0.26	0.12	0.53	0.01	0.06	0.086

The steel pipe No. 14 was found to have a slightly reduced stabilization ratio, but it did not reflect the reduced resistance to intergranular corrosion of steel in HAZ [4, 5, 6]. In the steel pipes No. 14 and 18, was found slightly increased content of phosphorus.

To produce corrosion cracks in tubular bodies made of austenitic steel was used method of exposure in melt of $MgCl_2.6H_2O$ [1, 7]. It is known that this method for high alloy austenitic steel is very sensitive to the presence of steel areas under the influence of tensile stresses (and residual). It was used for the tests the modified welds with artificial defects and without. Due to the impossibility of adjusting the cross-section of the test pieces with artificial defect in a suitable manner. The maximum tension was induced on the inner surface of the pipe by bending in the area of the notch - artificial defect, only for the tubular cutout No. 2 and 18 mm. The stress state was caused by static 4-point bending. Before the exposure, was performed a capillary test. Except to artificial defects, no indication was on surface found. Subsequently was performed exposure into the melt of $MgCl_2.6H_2O$. The total exposure time was 504 h (above 120 ° C), of which 336 h (above 145 ° C). The main objective of the experiment was to facilitate the initiation of cracks on pre-made primary defects [8 -10].

After exposure were founded cracks on both the inner and outer surfaces of the pipe, both in the heat-affected area of the weld-joint and on its free surface. At the specimen No. 2, which was stressed during the exposure by a four-point bend was founded cracks through the body (**Figure 2d**)). Detected defects are shown in the **Figures 2 a) -d**).

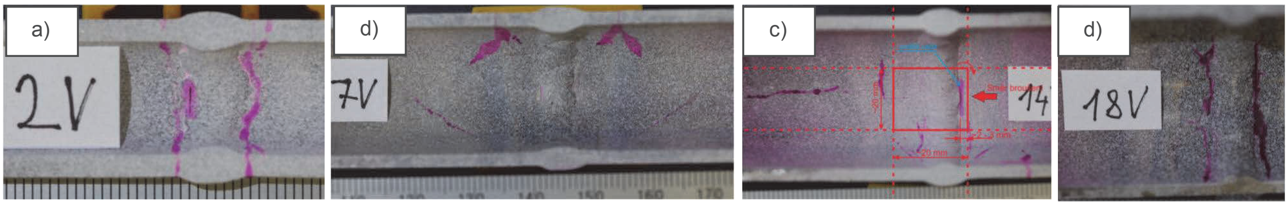

Figure 2 Appearance of inner surface of tubular bodies with detected defects

3. ANALYSIS AND RESULTS

For the macroscopic control of artificially created defects in the longitudinal direction, were specimens mounted into transparent matter. Subsequently, they were polished to half the width of the artificial defect. Macroscopic image documentation was obtained with a digital SLR camera with a macro lens. The scale in the photographs has a 0.5 mm divide. Measurements were made using the image analysis software. The overview of the obtained results is apparent from the data given, **Table 1**, **Figure 4**. All of the primary defects have been found to initiate the corrosion induced cracks, these were found on the free surface in the transverse direction and along the longitudinal direction. Both materials differ in their resistance to passivity due to activated Cl^- particles, but this did not occur in the strongly concentrated solution / melt of $MgCl_2$ [1, 12, 13].

A larger deviation from the intent is evident in the defect in the specimen 2, which was due to its location to the weld, so that the root of the weld already interfered, **Figures 3c, d**).

For the defect in the body No. 14, the defect was produced about 2 times greater than the intention. Specimen 18V showed the development of corrosion defects from the bottom of the artificial defect, **Figure 7d**). In the more detailed evaluation were found cracks initiated from the bottom of the artificial defects in all the bodies, **Figures 4 - 7**.

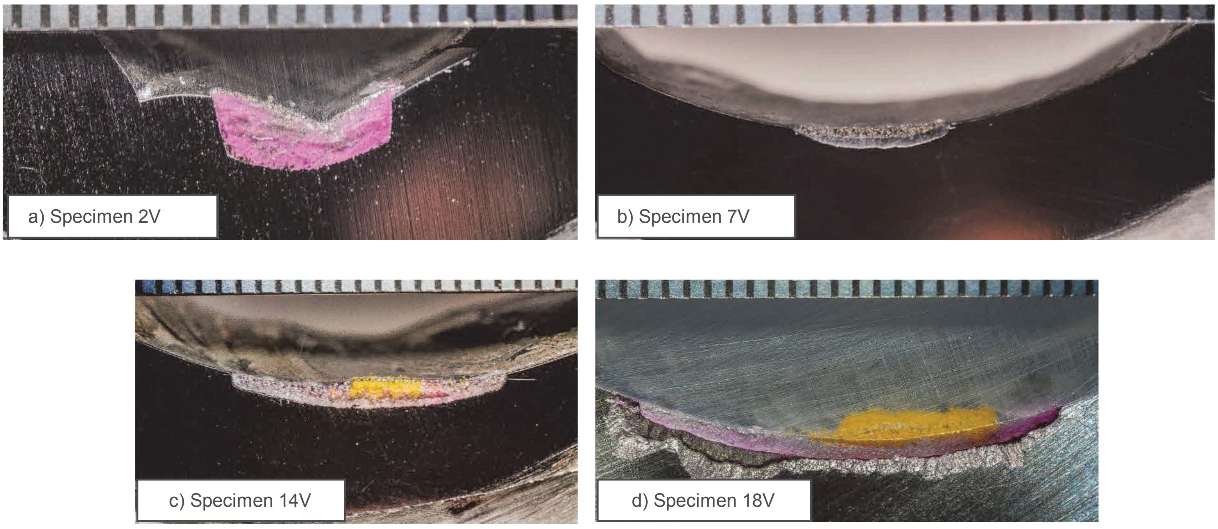

Figure 3 Appearance of the inner surface of tubular bodies with detected defects (cross-section of defects)

The metallographic documentation below shows cracks in the field of artificial defects. The metallographic images were obtained by standard, grinding and polishing followed by etching in V2 etchant.

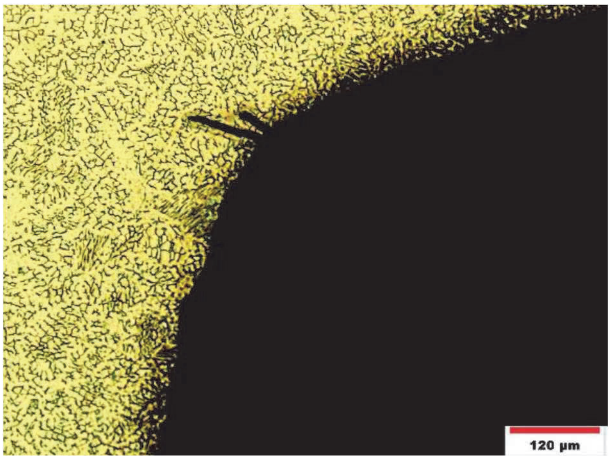

Figure 4 Specimen 2V

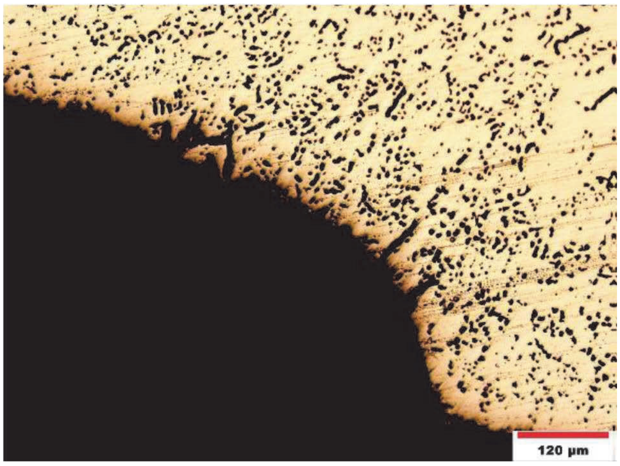

Figure 5 Specimen 7V

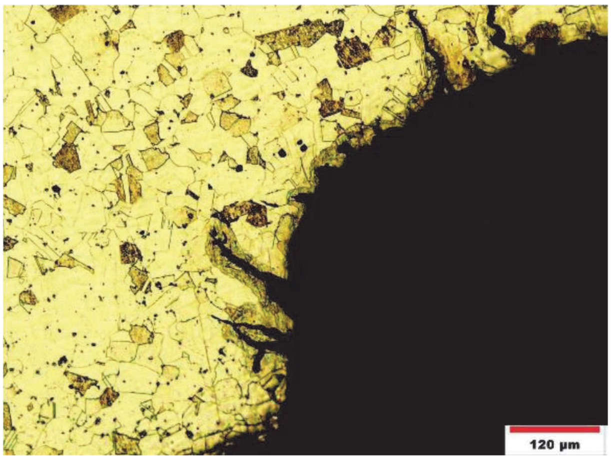

Figure 6 Specimen 14V

Figure 7 Specimen 18V

The following metallographic image (**Figure 8**) shows the formation of a corrosion crack in the 18V sample. This cutout is transverse to the weld compared to **Figure 7**. It is to be note that the crack is positioned in the heat-affected zone of the transverse weld of the tubular body.

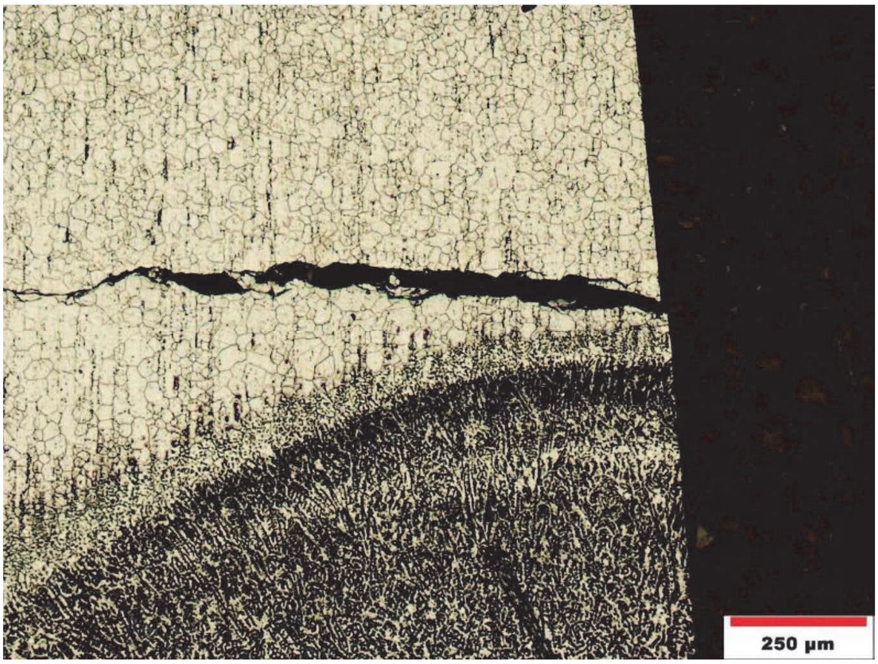

Figure 8 Crack in the HAZ area (specimen 18V)

4. DISCUSSION

The tube welding steels were made of austenitic stainless steel grades Cr18Ni10Ti and Cr18Ni10Mo2Ti (EN 1.4541 and 1.4571). In the conditions of expected application (cooling water circuit and primary circuit), these steels are located in areas where the criteria for the selection of corrosion-resistant and transition materials (temperature (200-350 °C) are to be applied, the criteria applicable to high [11]. In the different application areas of high-alloy steels, their long lifetime is conditioned by the presence of an oxidative barrier on their surface. Various mechanisms of formation of the oxidative barrier (on stainless steels is a passive layer, by the high-alloyed steels passes a passive layer to high temperature oxide) cause the state of the surface of the steel. On this surface, which is formed protective layer is manifested different way on the resulting durability of the material, ie its long-term stability under the operating conditions. The process used is also suitable as a "production" method for the verification of non-destructive techniques for detecting surface defects [10, 11].

5. CONCLUSION

When assessing the size of artificial defects, there was a greater divergence of the established facts from the intention. There was in the pipe No. 2 due to its location to the weld dimension and position. For the defect in the specimen No. 14, the defect was produced about 2 times greater than the intention. For the specimen No. 18 was the development of corrosion damage from the bottom of the artificial defect, **Figure 7**. A closer evaluation was observed crack initiated from the bottom of the artificial defects in all specimens, **Figure 4** through **Figure 7**. Larger cracks network originated in the heat-affected area at places with the highest residual stresses. Corrosion cracks also have a transgranular character in the initiation region. For cooling water (t <60 ° C), EN 1.4541 steel is less suitable than EN 1.4571 for higher risk of localized corrosion. This disproportion is more pronounced in the case of defects of welded joints communicating with the surface and unresolved / non-removable accompanying welding phenomena leading to deterioration of the physical and chemical surface conditions [4, 13].

The procedure can be used is also suitable as a standard and method for the verification of non-destructive techniques for detecting surface defects.

ACKNOWLEDGEMENTS

This paper was created in the Project LTI17023 "Energy Research and Development Information Centre of the Czech Republic" funded by Ministry of Education, Youth and Sports of the Czech Republic, program INTER-EXCELLENCE, subprogram INTER-INFORM.

REFERENCES

[1] ASTM G36 - 94(2013) Standard Practice for Evaluating Stress-Corrosion-Cracking Resistance of Metals and Alloys in a Boiling Magnesium Chloride Solution.

[2] ASTM G39 - 99(2011) Standard Practice for Preparation and Use of Bent-Beam Stress-Corrosion Test Specimens.

[3] DANKO, C. Stress Corrosion Cracking of Weldment in Boiling Water Reactor Service. *Chapter 15. Stress Corrosion Cracking, ASM*, 1992.

[4] BYSTRIANSKÝ, J. a kol. Hodnocení svarových spojů potrubních rozvodů TVN a TVD JE Temelín*, Zprávy VŠCHT Praha*, 2012 - 2016.

[5] KREYSA, G., SCHÜTZE, M. *Steam DECHEMA Corrosion Handbook - Revised and Extended 2nd ed.,* Frankfurt: Willey, 2008.

[6] WARZEE, M., et al. Effect of Surface Treatment on the Corrosion of Stainless Steels in High Temperature Water and Steam. *Journal of The Electrochemical Society*, 1965, vol 112(7): pp. 670 - 674.

[7] GORDON, B.M. The Effect of Chloride on the Stress Corrosion Cracking of Stainless Steels: Review of Literature. *Materials Performance 1980*, 19, (4), pp. 29 - 38.

[8] HIGUCHI, M., et al. A Proposal of Fatigue Life Correction Factor F for Austenitic Stainless Steels in LWR Water Environments. *Journal of Pressure Vessel Technology*, 2003, 125(4): 403 p.

[9] CHOPRA, O.K. and SHACK W.J. A Review of the Effects of Coolant Environments on the Fatigue Life of LWR Structural Materials. *Journal of Pressure Vessel Technology*, 2009, 131(2): pp. 21-409.

[10] SEIFERT, H.P., RITTER S., and LEBER H.J., Corrosion fatigue crack growth behavior of austenitic stainless steels under light water reactor conditions*. Corrosion Science*, 2012, vol. 55: pp. 61-75.

[11] WILHELM, P., STEINMANN P. AND RUDOLPH, J. Effects of Boiling Water Reactor Medium on the Fatigue Life of Austenitic Stainless Steels. *Journal of Pressure Vessel Technology*, 2016, 138(3): pp. 31-406.

[12] WARZEE, M., et al., Effect of Surface Treatment on the Corrosion of Stainless Steels in High Temperature Water and Steam. *Journal of The Electrochemical Society*, 1965, 112(7): pp. 670 - 674.

[13] BYSTRIANSKÝ, J., BÁRTA, J., TVRDÝ, M., MALANÍK, K. Determination of Condition Leading to Localized Corrosion Initiation on UNS S32100 Stainless Steel in Nuclear Power Plant Environments. *Nuclear Engineering and Design,* 1995, 157(1-2), pp. 123-136.