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STORAGE TANK INTEGRITY ASSESSMENT AFTER THE REMOVAL OF WELD CRACKS

OCENA INTEGRITETA REZERVOARA POSLE UKLANJANJA PRSLINA IZ ZAVARENOG SPOJA

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Abstract

Cracks located in the welded joint are detected during in-service tests of a liquid CO_2 storage tank made of micro-alloyed steel. It is estimated that cracks threaten future safe operation of the storage tank and must be removed. A possibility for removing the cracks by grinding has been considered without applying a weld overlay to areas of grinding, aimed at restoring the wall thickness. Non-destructive test results and results of stress state calculations by the finite element method (FEM) were used. It is concluded that future safe storage tank operation is possible without applying weld overlay deposits to areas where the cracks had been removed by grinding.

Izvod

Tokom eksploatacijskog ispitivanja rezervoara za skladištenje tečnog ugljendioksida, izrađenog od mikrolegiranog čelika, otkrivene su prsline u jednom zavarenom spoju. Ocenjeno je da prsline ugrožavaju dalji bezbedan rad rezervoara i da se zbog toga moraju ukloniti. Razmotrena je mogućnost uklanjanja prslina brušenjem bez naknadnog navarivanja mesta brušenja u cilju vraćanja debljine zida na početnu. Korišćeni su rezultati ispitivanja metodama bez razaranja i rezultati proračuna naponskog stanja metodom konačnih elemenata (MKE). Zaključeno je da je moguć dalji bezbedan rad rezervoara bez navarivanja oblasti iz koje su brušenjem uklonjene prsline.

INTRODUCTION

During the in-service tests of a liquid carbon-dioxide storage tank, cracks are detected in one of its welded joints. The tank is made of micro-alloyed steel S500NL (NIOVAL 50). It is well known that in the welded joints of pressure vessels made of this steel, cracks are detected in several cases /1, 2, 3/. Due to this, the in-service testing procedure, provided by regulations /4, 5/ in this case is supplemented with additional inspection of welded joints using magnetic particle and ultrasonic examination.

THE STORAGE TANK

The storage tank is a horizontal cylindrical pressure vessel with heat-insulation, of 50 m^3 in volume. It is made of steel of thickness 17 mm. Other basic information on the storage tank includes: maximum allowable operating pressure 20 bar, test pressure 26 bar, minimum service temperature –50°C, outer diameter 3000 mm, total length 7900 mm and vessel class II, /6/.

It can be seen from literature, /6/, that the joints located on the tank shell, as well as joints at the shell, header, and head are welded using the SAW procedure. The consumable used is a wire EPP 2NiMo2 along with flux OP 121 TT. Chemical composition and mechanical properties of the shell material segment where cracks are detected, is given in literature /6/ and in Tables 1 and 2 (see below). The chemical composition and mechanical characteristics of the consumable material is given in the same tables and in /7/.

Table 1. Chem. comp. of base- and consumable material (mas. %).
Tabela 1. Hemijski sastav osnovnog i dodatnog mater. (mas. %)

	C	Si	Mn	P	S	Mo	Ni	V
S500NL	0.20	0.51	1.42	0.020	0.010	0.017	0.574	0.18
EPP2NiMo2 OP 121 TT	0.05–0.08	0.20–0.30	0.7–1.0	–	–	0.45	2.0	–

Table 2. Mechanical charac. of base- and consumable material.
Tabela 2. Mehaničke osobine osnovnog i dodatnog materijala

	Yield stress $R_{p0,2}$ (MPa) min.	Ultimate strength R_m (MPa)	Elongation A_5 (%) min.	Toughness ISO – V min.
S500NL	547	738	28	27 J (–40°C)
EPP2NiMo2 OP 121 TT	450	650–750	20	30 J (–60°C)

RESULTS OF WELDED JOINT TESTING

The storage tank welded joints are tested visually, and with magnetic particles and ultrasonic testing, /8/. Visual inspection of the inner side of the vessel revealed misalignments at the shell-head joint, since the inner head diameter is smaller than the shell diameter /8/. Magnetic particle inspection of a misalignment has detected three cracks in a row on the fusion line, between the parent metal (PM) and shell segment.

The detected cracks are shown in Fig. 1. The indication is obtained by taking a transparent tape print of magnetic particles from the surface of the ground weld. The top line in the image represents an undercut, and the three lines in the lower part of the image represent three cracks that extend along the weld fusion line.

Figure 1. Cracks at the shell-head welded joint of the storage tank.
Slika 1. Prsline u zavarenom spoju omotača-danca rezervoara

The total length of detected cracks is 60 mm. Ultrasonic inspection is performed in order to measure the largest crack depth, which is 3 mm. A cross-section of the tank shell wall at the location of maximum crack depth is shown in Fig. 2. From this figure it can be seen that the cracks had developed at a location where, in addition to a 4 mm misalignment, there is also a sharp transition from weld face to the parent metal (PM).

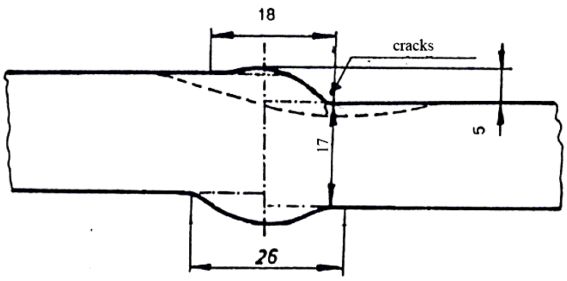

Figure 2. Cross-section of the tank wall at the location of cracks.
Slika 2. Poprečni presek zida rezervoara na mestu sa prslinama

It may be assumed that the cracks during the pressure tests or during tank exploitation, can merge with each other due to the small distance between them. This would lead to the formation of a larger crack which can in turn lead to leakage or failure of the storage tank. Thus, it is necessary to assess the effects of these cracks on the possibility of failure, i.e. the integrity of the welded joints where these cracks are located. The procedure presented in /9, 10/ is used for this assessment. It is concluded that the cracks endanger the further safe tank operation and therefore, must be removed.

PROCEDURE FOR REMOVING CRACKS

Cracks can be removed by grinding. Applying a weld overlay to the areas of grinding in order to restore the wall thickness to the initial state has been associated with difficulties. The NIOVAL 50 steel of 17 mm thickness needs to be heated up to around 200°C during welding and when applying the weld overlay. Heating of the steel requires that the heat insulation and the anti-corrosive protection must be removed from the outer side of the storage tank. Additionally, these layers are made of flammable materials in case of this particular storage tank. Other difficulties involve the qualification of weld overlay technology and the quality assurance of the weld overlay location. Quality control specimens with a welded joint., or sufficiently large PM plates are necessary for the qualification of the weld overlay technology, /11/. Neither of the two has been available in this case. The NIOVAL 50 steel has a cold cracking susceptibility in the HAZ. In such case, the conditions at which the weld overlay is applied go in favour of cold cracking susceptibility, since WM cooling undergoes a constrained shrinkage, resulting an increase in tensile stresses in the HAZ, and therefore leads to the appearance of cold cracks. The quality assurance of the weld overlay location is made only by applying non-destructive testing (NDT) techniques. These techniques have only limited possibilities when it comes to microstructure and hardness tests, as well as when determining strength and plasticity characteristics of the welded joints. Due to everything mentioned above, the possibility of further safe operation of the storage tank is considered after the removal of cracks by grinding, without applying an additional weld overlay to areas grinding.

STRESS STATE ANALYSIS OF GRINDING AREAS

In order to assess further safe operation of the storage tank, it is necessary to determine stress states at locations where the cracks are removed. Stresses acting in this area are caused by internal pressure, and residual stresses in the welded joint.

Two operating regimes of the storage tank are distinguished in further storage tank exploitation. The first involves the pressure test using internal pressure and the second involves operating conditions. During internal pressure, the storage tank is at the test medium temperature, in this case water, between 10 and 20°C, and at 26 bar pressure. In operating conditions, the storage tank is at temperatures between –20 and –30°C and is subjected to pressures ranging from 14 to 20 bar. Considering that a decrease in temperature leads to a drop in pressure which decreases the stresses in the tank wall, then the material toughness also decreases, but not beyond minimum guaranteed value (27 J), whereas material strength increases to a certain level. Thus, conditions that shall be assessed as critical relate to the internal pressure test, hence the stress state for such conditions is further assessed.

The stress from the pressure inside the storage tank, P_m, causing cracks to appear and develop along the joint between the head and shell, i.e. in direction perpendicular to the tank axis is determined according to the following formula: $P_m = pD/4B$, where p = 26 bar is the test pressure; D = 3000 mm is the outer shell diameter; and B = 17 mm represents the wall thickness. The pressure calculated in this way is P_m = 115 MPa.

Stresses developing from a decrease in the wall thickness and the change in shape of the area where cracks had been removed are determined by applying the finite element method (FEM). Sizes of this area are given in Fig. 2. The dotted line in the figure represents the defined profile of the ground area. In order to reduce stress concentration, the transition from thinner to thicker cross-section needs to be smooth and gradual. This part of the tank is modelled by two-dimensional finite elements, Fig. 3. The right end of the model has constraints along the direction of the *x* axis, with no displacements, whereas the left side is composed of forces that correspond to a stress of 115 MPa. Numerical results are shown in the same figure, as areas with different stress values are distinguishable by colours. The largest stress, 348 MPa, equals the sum of stress P_m, the stress caused by reduction of wall thickness and the stress due to the change in shape, occurs at the transition between WM and PM, i.e. in the area where cracks have been detected.

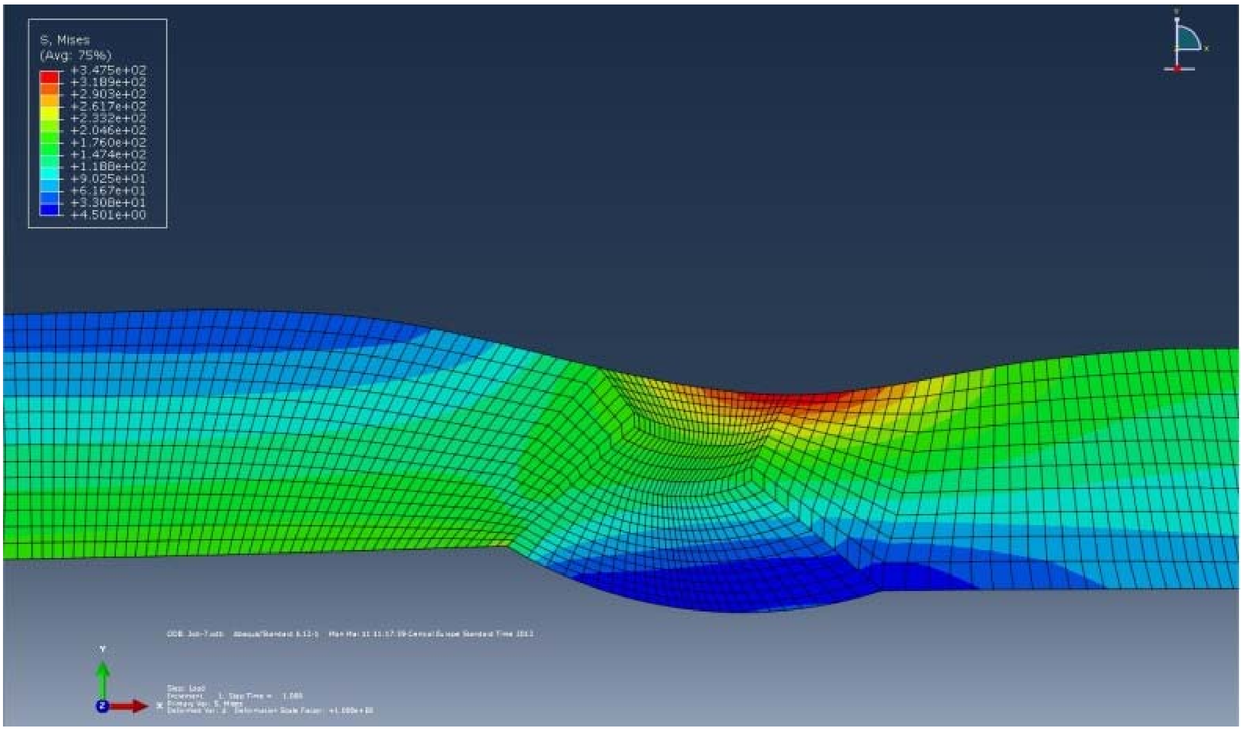

Figure 3. Stress distribution in the area where cracks are removed.
Slika 3. Raspodela napona u oblasti iz koje su uklonjene prsline

It can be seen from literature, /6/, that the storage tank is not stress annealed. In this case, according to /9/, the maximal value of residual stresses is equal to the lesser of the values of yield stress for WM and PM. Table 2 shows that yield stress of the weld metal is lower and equals around 450 MPa. According to /9, 12/, even in the case of stress annealing, residual stresses in welded joints cannot be reduced below 30% of their initial value. However, even in the case of structures that are not stress annealed, the level of residual stresses can still be reduced considerably using various measures applied during the weld technique, /12/, (e.g. preheating, maintaining interpass temperature, welding torch movement with whipped motion). Steel S500NL must be welded with the use of preheating and maintaining the interpass temperature, /6/. The applied EPP procedure does not allow welding torch movement with whipped motion. Owing to this, it is adopted that residual stresses are reduced by 20% compared to the yield stress of the WM and are equal to 360 MPa.

The maximal tensile stress at the location of the smallest wall thickness is equalled to the sum of residual stresses (360 MPa) and the highest stress at the location of flaws (348 MPa), i.e. it equals 708 MPa. This stress is lower than the ultimate tensile strength of the PM, Table 2, thus cracks should not reappear in this zone. The difference between the ultimate tensile strength of the PM and the maximal tensile stress is 30 MPa, i.e. 4%. This difference is small and cannot on its own provide a sufficient guarantee that cracks will not reappear.

In this sense, additional tests using NDT methods are required. During the internal water pressure tests, the storage tank has also been tested by acoustic emission, whereby crack- initiation or propagation signals have not been detected. Upon pressure testing and after several years of storage tank exploitation, /13/, magnetic particle and ultrasonic tests once again have been performed at the location where the cracks were removed, and none were detected.

CONCLUSION

During in-service testing of a storage tank, cracks are detected in welded joints. Assessments showed that these cracks endanger further safe operation of the storage tank and had been removed by grinding. Restoring the tank wall thickness to its original state by applying weld overlay involved numerous difficulties. Because of that, the possibility of further storage tank exploitation without applying a weld overlay to the area where cracks had been removed was taken into consideration.

The stress state in this area is determined based on residual stresses in the welded joint and stresses caused by the reduction in thickness and the change in shape of the wall. Residual stresses are evaluated, whereas stresses due to the reduction of thickness and shape change are determined using the finite element method (FEM). Maximal stress was found less than the ultimate tensile strength of the material that the shell segment with cracks is made of. Hence, it is assessed that further safe operation of the storage tank is possible without applying a weld overlay to the area where the cracks had been removed by grinding.

The small difference in maximal stress and ultimate tensile strength of the tank shell segment material, where the cracks had appeared, yet does not provide for sufficient further safe operation assessment. Thus, additional NDT tests were necessary and have shown that the cracks did not reappear during the pressure tests, as well as during the following five years of storage tank operation.

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