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RESIDUAL STRESS EFFECTS ON METHANOL STORAGE TANK INTEGRITY

UTICAJ ZAOSTALIH NAPONA NA INTEGRITET POSUDE ZA SKLADIŠTENJE METANOLA

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- integrity
- methanol
- stress corrosion cracking

Ključne reči
- posude pod pritiskom
- integritet
- metanol
- prsline usled naponske korozije

Abstract

The purpose of this paper is to present the impact of improper choice of procedure for repairing a pressure vessel for methanol storage, that could finally lead to failure. Presented information is based on the results of inspection activities from an oil and gas plant. Anyhow, these types of problems can appear in industrial units treating, or using methanol for various purposes, especially in cases when residual stresses are significant enough to cause damage mechanisms and create cracks on pressure vessels or pipelines.

Izvod

Svrha ovog rada je da se prikaže uticaj nepravilnog izbora procedure za reparaciju posude pod pritiskom za skladištenje metanola, što može da dovede i do njenog trajnog oštećenja. Prezentovane informacije su bazirane na rezultatima inspekcijskih pregleda u okviru postrojenja za preradu nafte i gasa. Ovakvi problemi se mogu javiti u industrijskim jedinicama koje tretiraju ili koriste metanol u različite svrhe, posebno u slučajevima kada su zaostali naponi dovoljno veliki da izazovu oštećenja, tj. stvaranje prslina u posudama pod pritiskom ili cevovodima.

INTRODUCTION

Methanol also known as methyl alcohol (CH_3OH) is an organic chemical compound extensively used in various industries. Some of the most frequent applications are:
- as a solvent (in the production of paints, plastics, explosives, streptomycin, vitamins, etc.);
- in wastewater treatments (converts dangerous nitrates to harmless nitrogen);
- as an antifreeze (reduces the freezing point of a water-based liquids);
- as an inhibitor in pipelines of natural gas, especially in cold weather facilities, /1, 2/.

On the other hand, this multipurpose chemical compound could be very aggressive especially in combination with stress that may be present in metal structures (pressure vessels or pipelines). Mentioned stress could be even residual or applied stress. Under these conditions, it is likely that *stress corrosion cracking* (SCC) will occur. Highly stressed, locally cold worked components (for example elliptical heads after cold forming), or parts with local stress concentrators, are susceptible to this type of cracking. Regarding materials, all grades of carbon steel are susceptible to this type of corrosion. On the other hand, methanol SCC has not been reported in materials other than carbon steel, but general corrosion may be a concern with other materials, including some alloys of aluminium, copper and copper alloys, lead, and zinc, /1, 3/.

INITIATION OF A PROBLEM

The vessel under consideration is part of the unit for gas treatment (sweetening unit) and is used as a tank for methanol that is predicted to be consumed during the winter period. Material of the vessel is carbon steel A516 Gr.60 (P-No 1 & Group No 1). The vessel has a volume of 11.3 m^3 (d = 2.15 m, h = 3.5 m), and wall thicknesses 15.0 mm (cylindrical shell) and 13.5 mm (elliptical heads), /2/. As per manufacturer, post weld heat treatment (PWHT) has not been predicted for the vessel, in accordance with ASME Section VIII (Rules for Construction of Pressure Vessels). Obviously, this decision was the trigger for the events that will cause further problems because methanol impact on the metal has not been taken into consideration. One of the main reasons to avoid PWHT of the vessel was probably the reduction of fabrication costs, without considering the aggressive nature of methanol, /3-5/.

As a result of all these facts, intensive degradation at the critical points, in this case circumferential welded joint, started immediately after putting the vessel into service, and during first inspection. After only 3 years in service, cracks have been observed on the mentioned joint between the shell and lower elliptical head. The location of cracks is indicated in Fig. 1. After internal inspection, numerous transverse cracks are found on the circumferential welded joint. Penetrant tests have been performed as one of the inspection methods. Discovered cracks were located in the welded face, as well as in the base metal (Fig. 2).

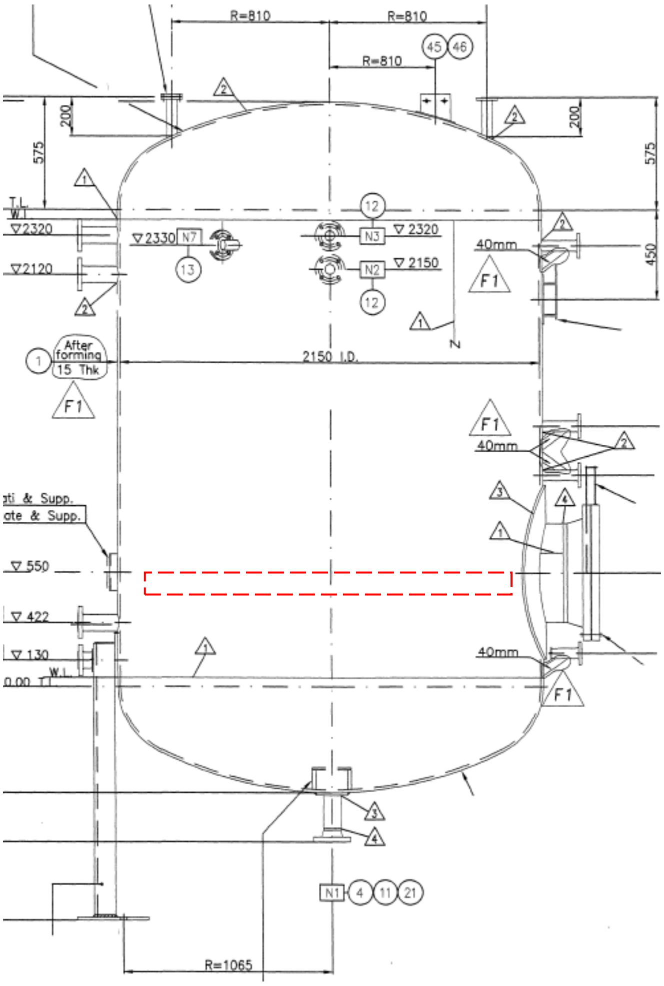

Figure 1. Vessel scheme.

It should be emphasized that this type of corrosion as a result, typically has very narrow cracks filled with corrosion products, and for that reason it is very difficult to see them without the use of some non-destructive inspection methods, like penetrant, magnetic, or ultrasonic testing. These cracks could be so narrow that small leaks may occur even before cracks can be visually detected.

Figure 2. Transversal cracks in the circumferential welded joint.

Except for the marked welded joint (Fig. 1), all other joints were in good condition and without any abnormalities like pitting corrosion, localized corrosion, erosion, etc. Internal surfaces were only subjected to light uniform corrosion, and according to the measurements, wall thicknesses were still according to design parameters.

WRONG APPROACH TO PROBLEM SOLVING

After discovering the cracks it was concluded that some kind of action should be performed in order to minimize any possibility of methanol leakage. Although design pressure is 12 bar, in fact operating pressure was much lower (less than 3 bar). This fact led to the wrong conclusion that it would be enough to install welded patches on the vessel to make it operational and safe enough for plant needs. This step was done without any deeper analysis of the problem, as shown in Fig. 3.

Figure 3. Installed welded patches.

A result of this unprofessional approach to problem solving in a very short period of time (just a few months) was the leaking noticed by operating personnel. After this event, internal inspection was performed in order to check the extent of damage.

Intensive welding activities (without any heat treatment) resulted in additional increase of internal stress, and finally, in combination with aggressive influence of methanol had resulted in the creation of new cracks (Fig. 4). Cracks appeared on the knuckle region of the elliptical head where internal stress due to cold forming and additional stress due to welding activities, resulted with initiation of cracks.

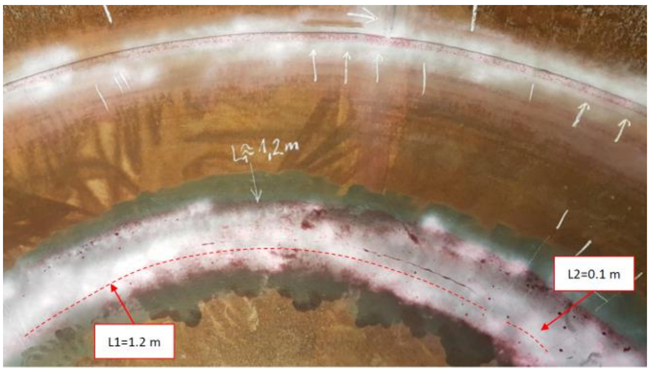

Figure 4. Location of cracks in the elliptical head.

How large was the impact of additional stress can be concluded from the size of these new formed cracks. The length of the largest was 1.2 m. The remaining two had lengths of 0.1 and 0.3 metres. Among these, new cracks were formed on some nozzles near welded patches. Anyhow, they were not as large as the previous ones (Fig. 5).

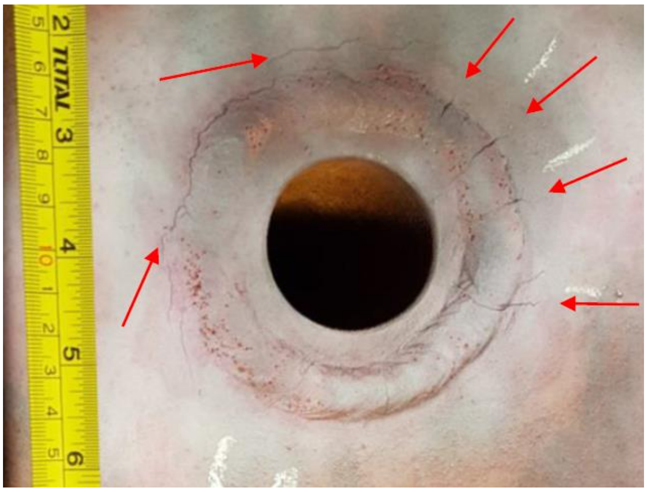

Figure 5. New cracks appeared on nozzles near the welding zone.

The final result of these actions was a vessel that cannot be used anymore and has to be replaced with new one. In order to minimize the possibility for similar problems, heat treatment was strictly demanded for the new purchased vessel.

APPROPRIATE APPROACH TO PROBLEM SOLVING

As many systems in plants, also in this case the methanol supplying system is doubled (while one is operating, the second one is in standby - and vice versa). For that reason, it was essential to define the condition of the second pressure vessel for methanol and to ensure the continuity of supplying methanol. Having in mind the results of previous actions, more rigorous analysis was carried out, and a different approach in vessel repair, and eventually further protection was proposed. Shortly, this new proposal is presented in these steps:

- removal of all discovered cracks by careful grinding till bare metal;
- after grinding, it should be confirmed by using appropriate NDT methods (PT, WFMT, or shear wave UT) that all cracks have been removed successfully;
- to perform thickness measurements (UT scanning) of the areas where grinding was performed, in order to determine the remaining thickness of the metal.

In the case that cracks are not too deep, and the remaining thickness after grinding is still above minimal required, two steps can be performed:

- heat treatment of the vessel, or
- protection of all internal surfaces using an appropriate coating system that is resistant to methanol.

The protective coating demands lower costs, so in cases like this it is always a preferred method. On the other side, in the case that remaining thickness after grinding is below required values, metal build up should be performed using an appropriate welding procedure (WPS). Certainly, after welding activities, proper post weld heat treatment (PWHT) is necessary. Of course, PWHT cannot reduce the levels of tensile residual stress to zero, but in a very well controlled thermal cycle, they can be reduced approximately to 30 % of material yield strength, /6-8/.

In the industrial environment, the PWHT is usually conducted using induction heating blankets, and the heat is generated by induced alternating magnetic field in the electrically conductive material, /8/. This equipment is preferred because of many reasons:

- simple and flexible to operate,
- equipment requires minimum maintenance,
- low heat losses and running costs,
- available to suit metallic vessels of most forms and shapes, and above all,
- consistent product quality.

Induction heating embodies all the conveniences of electricity taken directly to the process and transformed to heat exactly where it is required. Since the heating takes place directly in the vessel wall in contact with the product, and heat losses are extremely low, the system is highly efficient (up to 90 %).

APPLYING THE PROPOSED PROCEDURE

After the inspection of the second vessel it was found that the condition and damage mechanisms are almost the same as in the previous one. It means that only the circumferential joint between the shell and elliptical head is affected by methanol corrosion, as shown in Fig. 1.

The detected cracks were transverse to the welded joint and very narrow. Light pitting corrosion was also detected, Fig. 6.

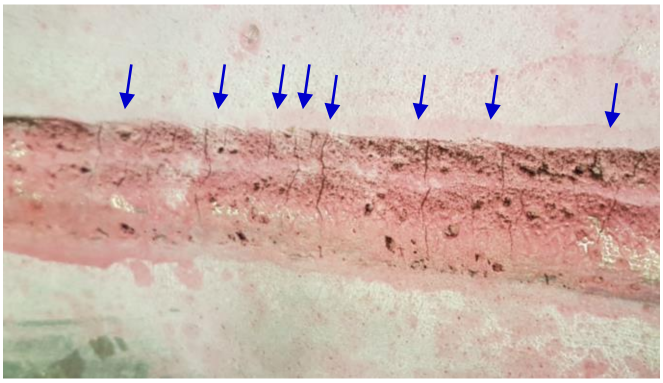

Figure 6. Condition of the welded joint with tiny cracks, perpendicular to weld direction.

According to the new repair procedure, the first step was to remove all detected. During grinding, from time to time, penetrant tests were performed in order to determine whether additional grinding is necessary, i.e. if all cracks have been removed or not (Fig. 7). Of course, at the end of the process all surfaces were made to be smooth in order to minimize stress concentration (Fig. 8). After grinding, thickness measurements were performed in order to confirm the remaining thickness of the material.

As shown in Table 1, all remaining thicknesses are still above design values, and it is concluded that the vessel can still be used after the methanol environment protection.

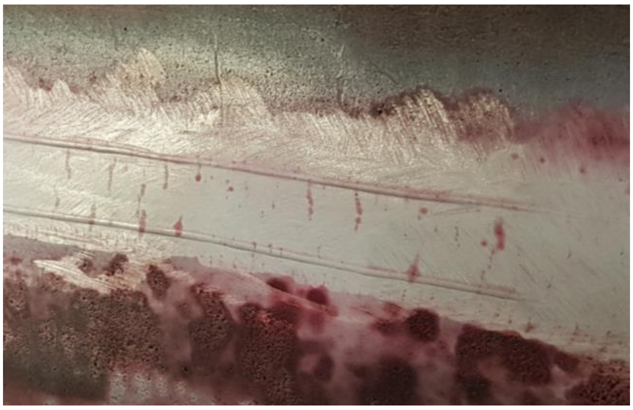

Figure 7. Condition of the circular joint during the grinding process and crack removal (traces of cracks can still be noticed).

Figure 8. Condition of the circular welded joint after grinding and crack removal.

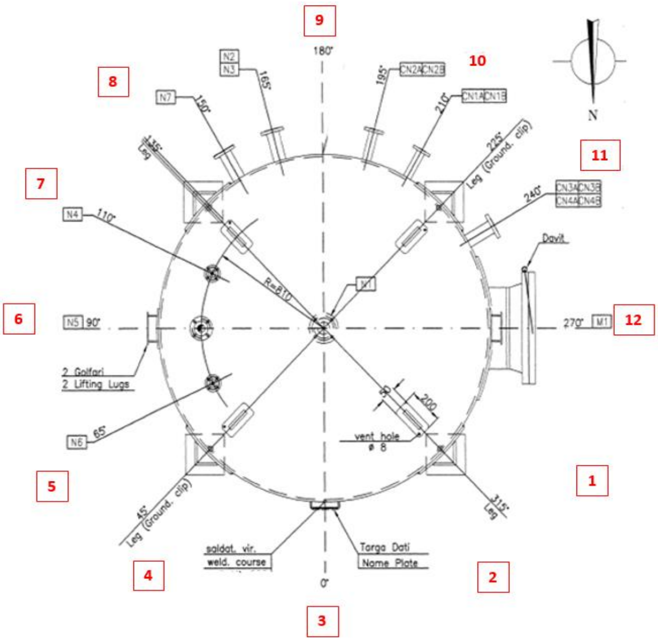

Figure 9. Location of UT scanning positions.

Table 1. Measured thickness after grinding of the weld joint.

Location	1	2	3	4	5	6
Thickness (mm)	15.5	17.0	15.0	13.8	15.8	14.0
Location	7	8	9	10	11	12
Thickness (mm)	13.9	16.8	15.8	17.0	15.8	17.3

The final step was to protect the internal surface with an appropriate coating system resistant to methanol. To ensure good paint adhesion, all surfaces were cleaned, dried, and free from any contamination. The internal surface was sand-blasted to preparation grade Sa 2-1/2 (very thorough blast-cleaning) according to ISO 8501-1 (*Corrosion Protection of Steel Structures by Painting*). Two-component moisture curing inorganic zinc ethyl silicate was chosen for surface protection. Air spray was used as application method, and after finishing the reparation, a dry film thickness of 150 μm is measured (recommended from 70 to 170 μm). As additional information, internal inspection of the vessel was performed after 1 year in service, and the integrity of the applied coating system has been confirmed, as well as the integrity of the repaired pressure vessel.

CONCLUSION

Having in mind the presented facts on residual stresses and repair procedures, it can be concluded that all methanol storage or transportation equipment requires heat treatment, preferable whenever possible. For sure, this will increase the investment price, but on the other side, it will minimize problems in service life. As an option for larger equipment (pressure vessels, storage tanks), special protective coatings, resistant to methanol can also be used.

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