Marin Beloev, Nikolay Lolov

Selected Technological Features Concerning Welding in Making of the Ammonia Tanks

Abstract: The article discusses factors connected with the stress corrosion cracking of ammonia storage tanks and presents the details of a welding technology ensuring the obtainment of the maximum service life of these tanks.

Keywords: amonia storage tanks, stress corosion cracking, welding of storage tanks

DOI: 10.17729/ebis.2016.5/14

The storage of dangerous goods in tank capacities has received special attention from operational staff. This fact results in the specific requirements that the contractors place upon designers and manufacturers of these facilities. Dangerous goods are those which in their uncontrolled release to soil, water and air can cause catastrophic consequences to people and the environment. Tank capacities are used for a variety of goods such as acids, alkalis and gases. In particular, ammonia tanks are often built and hide similar hazards.

What is anhydrous ammonia?

Anhydrous ammonia is a gas with a pungent odour and is most commonly used in the nitrogen fertilization of cereals - maize, wheat and oats. It is also used as a refrigerant in the food industry. When heated, it may explode. Exposure to even small amounts of anhydrous ammonia can cause severe burns of the eyes, nose and throat. Exposure to larger amounts causes coughing or choking, and can lead to death by the swelling of the throat or burning of the lungs. Ammonia is an extremely hazardous product and leads to catastrophic gassing. For example, in the United States, during the years 1996 and 2011, there occurred almost 1000 accidents with 678 tanks storing large amounts of anhydrous ammonia. These accidents resulted in 19 deaths; 1651 people have received serious burns and the value of losses was $350 million [1]. It was found that one of the main causes of accidents with tanks of anhydrous ammonia during normal service is **stress corrosion cracking** (SSC) [2]. The cracks propagate mainly through the grains and usually are observed in steels with high strength and hardness. Observations have shown that the cracks are mostly associated with welded joints, where the HAZ hardness is higher than the hardness of the base metal and weld and where tensile residual stresses exist. Post weld heat treatment (PWHT) reduces residual stresses and SCC, but its application is often not possible due to the large size of the tanks. Furthermore, the heat treatment after the introduction of tanks in service can be ineffective, as already initiated cracks have sufficient intensity of stresses at their tips that support the crack propagation.

Marin Beloev – Consortium KZU Holding Group, Sofia, Nikolay Lolov – Technical University, Sofia, Bulgaria

Necessary measures in designing ammonia tanks

Factors contributing to the formation of SCC can be divided into three groups: tank material. active medium and stresses.

Tank material

In terms of the material, the following factors should be taken into account: type of material, mechanical properties and chemical analysis, microstructure, deformation and surface condition.

For the production of anhydrous ammonia tanks, plates of low-carbon, low-alloy steel with nominal yield strength not higher than 355 Mpa are recommended [3]. The actual yield strength should not exceed 440 MPa and elongation A_5 has to be higher than 22%. It is recommended that the chemical composition be within the range indicated in Table 1. The steel must be of fine grain structure obtained after normalization.

The same requirements for the chemical composition and the mechanical properties apply to any additional elements such as inner tubes, nozzles, dished ends, etc. It is recommended that dished ends are to be made by hot plastic deformation, but if they are cold pressed then they have to be subjected to normalization.

All parts of the pressure vessel must meet the requirements for impact energy shown in Table 2.

Active medium

In terms of the active medium the following factors should be taken into account: the type of medium, contamination, temperature and electro-chemical condition:

Anhydrous ammonia is stored at a temperature from ambient to -33°C. SCC is influenced significantly by the presence of oxygen and water in ammonia [2]. In all cases, cracking is related to the presence of oxygen. The cracking tendency rises with the increase in oxygen content and decreases with water content (Fig. 1). It is normal practice to use water as a corrosion inhibitor. The use of water in the low temperature systems is not always effective. In the zone

Table 1. Chemical composition for fine grain Steels, Ladle Analysis[1)]

% maximum (if not otherwise indicated)										
C	Si	Mn	P	S	Al	Cr	Cu	Mo	Ni[2)]	V
0.18	0.10-0.50	1.65	0.030	0.025	min. 0.020	0.20	0.35	0.08	0.40	0.10

[1)] For steels with a nominal yield point of 355 N/mm², the chemical composition is to be adjusted in such a way as to limit the actual yield point to 440 N/mm²

[2)] If nickel is intentionally used as an alloyed, the maximum may be 0.85%

Table 2. Impact Energy Requirments in ISO V-notch specimens

Type of product	Test temperature [°C]	Impact Energy[1)] Joule, min.	
		longitudinal	transversal
Plates	-20	-	27
Pipes		41	-
Forgings		41	27

[1)] Average value. One value may be below the average value, but not lower than 70% of this value

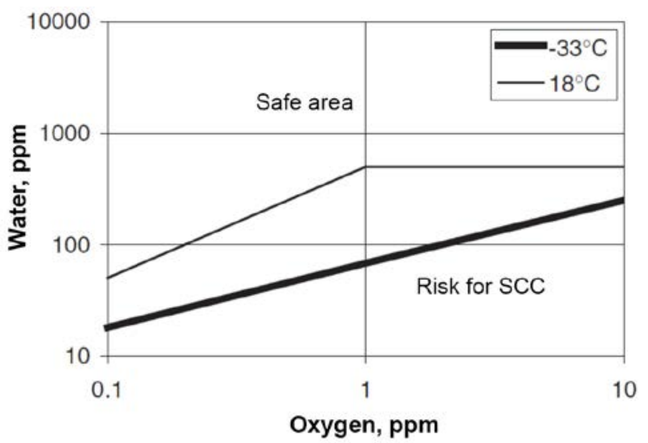

Fig. 1. Relationship between the water content and oxygen in the ammonia and the risk of SCC [4]

of the vapour phase at the upper inner surfaces of the tanks, a condensate with a reduced water content is formed and thus with a reduced inhibitory effect.

Under normal operating conditions of the refrigerated ammonia reservoir, the oxygen content should be below 0.5 ppm, and the water content between 100 and 1000 ppm.

Stresses

In terms of the stresses, the following should be taken into account: residual stresses resulting from the manufacturing process, including the welding stresses. The surface tensile residual stresses play a special role in the SCC. For this reason, attention should be paid to methods of their reduction.

Features of welding technology to ensure maximum durability of welded structures

For maximum durability of ammonia tanks subjected to SCC, it is necessary to develop and implement a welding technology fulfilling a number of conditions related to the selection of welding materials and welding parameters.

For manual arc welding, low hydrogen basic electrodes (diffusion hydrogen content less than 8 ml /100g) should be used. Filler metal that does not contain molybdenum and vanadium is only permitted, see Table 1. The strength of the weld metal must exceed the strength of the base metal by as much as possible. The hardness of the weld as well as that of the heat affected zone should not exceed 230 HV. This fact should be confirmed in testing and approval of the procedure. A minimal preheating should be used in order to keep the welding stresses and the welded joint hardness lower. Preheating and interpass temperature should not be less than 100°C and all welding work must be carried out using the multipass technique. Imperfections associated with the tank structure assembly should be avoided because they can cause localized stresses. For this purpose, the tank manufacturer must clarify the technical conditions for the tank, pointing out the permitted production tolerances. Welding defects such as excess weld reinforcement and arc ignition spots on the base metal must be removed by grinding. All butt welds on the tank walls should allow for ultrasound inspection. If necessary, the surfaces of welds must be grinded. The following measures should be taken for an ultrasound inspection to be carried out:

- Both sides of the welds of crossing joints are to be ground flush with the surrounding plate surface on a length of at least 500 mm starting from the crossing point;
- The full penetration welds of domes and sumps with the tank shell are to be ground on both sides.

The quality of the welds must comply with the pressure vessel standard approved by the consumer.

Methods to relief the welding stresses

A major factor for SCC of the ammonia tanks is the presence of residual tensile stress in the inner surface. Thus, increasing the life of tanks requires the application of effective methods for residual stress relieving.

Thermal methods for relieving residual stresses

In this traditional method, the part is heated under carefully controlled conditions to several hundred degrees, maintaining this state till the majority of the stresses have been relieved. It is then followed by controlled cooling to prevent the introduction of new residual stresses. In many cases, this process is reiterated many times during the manufacturing process before the part is ready for use. During this process, the yield point of the material is substantially lowered, which allows for plastic flow in the material. This plastic flow in the material, consequently, causes redistribution and subsequent reduction of internal residual stresses. Although thermal methods have been widely used in industry, they have their own limitations in certain situations. In some cases, the cost of treatment of the part is very high in terms of energy and capital required. Additionally, oxide scales on the surface are formed that require subsequent finishing processes, further increasing the overall cost. In many cases, the initial "design" material properties are lost during thermal stress relief [5].

Specifically, for steel grades used for the production of ammonia tanks, a heating to 570 + 20°C and holding at this temperature for an hour is recommended. When the size of the furnace or equipment for heat treatment does not allow for the heat treatment of the entire tank, a separate heat treatment for stress relieving of domes, trunks and hatches together with the parts around the tank is recommended before assembling them to the tank and then mechanical stress relieving of the finished tank is performed. After stress relieving, welding work on the inner wall of the tank should not be carried out. A light grinding can only be done. After mechanical stress relieving, the hardness of the weld intersection on the tank wall should be tested. If the hardness value exceeds 230HV, supplementary activities must be carried out [3].

Shot peening

In shot peening, spherical pellets are bombarded on the surface whose residual stresses need to be reduced. These pellets are usually small spheres of steel, ceramic or glass, which are pneumatically propelled on the surface. These bombardments create deformations on the surface of the part, which induce compressive and tensile stresses in the surface and sub-surface of the part respectively [5]. These compressive stresses in turn increase the component's resistance to SCC.

Vibratory stress relief

This process subjects the workpiece to vibration at a particular frequency and amplitude for a pre-determined time interval. The combination of this external force and workpiece's internal stresses causes it to cross its yield point, thereby resulting in plastic flow. This leads to redistribution and reduction of residual stresses. Vibratory techniques have several benefits such as the ability to handle large components in a timely and cost effective manner. Depending upon the size of the components, there are two types of setups to impart vibrations to the component. If the structure is sufficiently large, the vibrator can be clamped directly onto it. The motor is then energized to vibrate the component. In the case of smaller components, the stressed body can be placed upon a table, which is isolated with anti-damping mechanisms and the vibrator is then attached to the table top [5].

Ultrasonic peening (UP)

The UP is an effective way to relief harmful tensile residual stresses and to introduce beneficial compressive residual stresses in surface layers of parts and welded elements. The UP technique is based on the combined effect of the high frequency impacts of the special strikers and ultrasonic oscillations in the treated material. During the ultrasonic treatment, the striker oscillates in the small gap between the end of the ultrasonic transducer and the treated specimen, impacting the treated area [6].

In general, the effect of ultrasound on the mechanical behaviour could be compared with the effect of heating on a material. The difference is that acoustic softening takes place immediately when a metal is subjected to ultrasonic irradiation. Also, relatively low-amplitude ultrasonic waves leave no residual effects on the physical properties of metals after acoustic irradiation is stopped [6].

The ultrasonic transducer oscillates at a high frequency, with 20-30 kHz being typical. The ultrasonic transducer may be based on either piezoelectric or magnetostrictive technology. Whichever technology is used, the output end of the transducer will oscillate, typically with an amplitude of 20-40 µm [6].

In SCC resistance improvement, a beneficial effect is achieved mainly by the introduction of the compressive residual stresses into surface layers of metals and alloys, the decrease in stress concentration in weld toe zones and the enhancement of the mechanical properties of the surface layer of the material. The schematic view of the cross section of material/part improved by UP is shown in Figure 2 with the attained distribution of the stresses after the UP.

The basic UP system shown in Figure 3 could be used for treatment of weld toe or welds and larger surface areas if necessary [7]. The speed of processing is in the range of 0.4 m/min.

Residual stresses REDUCTION with LTT electrodes

To reduce residual stresses, some authors [8] recommend the use of electrodes with a low transition temperature (LTT electrodes). Recently, welding consumables are developed that can create compressive residual stresses in the weld toe through martensite transformation. These compressive residual stresses may be significantly larger than stresses generated by the thermal or mechanical treatment of the welded joints.

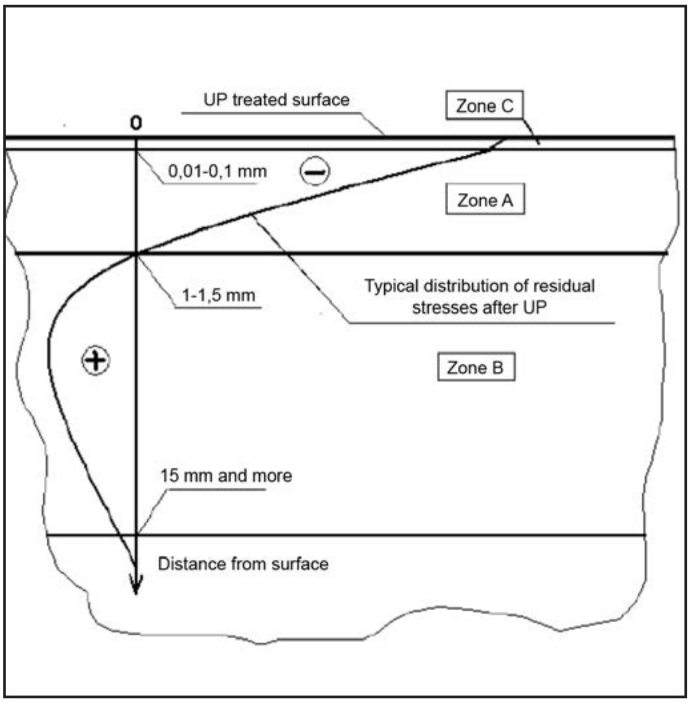

Fig. 2. Schematic view of the cross section of material/part improved by Ultrasonic Peening [9]

Martensite transformation start (Ms) and finish (Mf) temperatures are essential parameters in residual stress development in the weld. In the normal processing of a typical structural steel weld, the contraction of the weld metal occurs as the weld joint cools down, leading to the induction of tensile residual stresses. The expansion that accompanies martensite transformation can counteract and mitigate the effects of thermal contraction. The transformation temperature, Ms, can be adjusted by means of varying the chemical composition, in particular, nickel and chromium. Alloy composition is critical to the generation of compressive residual stresses and also the magnitude of these stresses. If martensite transformation occurs at a high temperature, the thermally induced contraction that takes place between this temperature and room temperature may likely exceed martensite expansion, precluding the establishment of a final compressive residual stress state. Thus, it is preferred that martensite transformation initiates at a temperature as low as possible and finishes just above the final temperature to which the weldment is expected to cool [8]. Despite the good results there is so far no evidence of the use of LTT electrodes in the production of ammonia tanks.

Measurement of residual stresses

After processing the structure to relieve or reduce residual stresses, there is a need to establish whether this treatment is effective and

Fig. 3. Basic ultrasonic peening system for treatment of welded elements and structures [7]

whether it yields results. There are two groups of techniques for measuring residual stresses: destructive and non-destructive techniques. The first group of techniques (through destruction) is based on the alteration of the equilibrium state of residual stresses in the structure after cutting, removing the surface layer, or hole punching. Obviously these techniques are not suitable for the ammonia tanks. Non-destructive techniques include: X-ray and neutron diffraction methods, magnetic and ultrasonic methods.

X-ray and neutron diffraction methods.

These methods are based on determining the change of the crystal lattice parameters as a measure of the elastic deformation, which is caused by residual stresses.

Magnetic methods

These methods are based on the interaction between the elastic deformation and magnetization in ferromagnetic materials. It can use different magnetic properties such as permeability, magnetostriction, hysteresis or Barkhausen noise.

Ultrasonic methods

These methods are promising for the development of non-destructive techniques for measuring residual stresses. They are based on acousto-elastic effects and thus the speed of propagation of elastic waves in solids becomes dependant on the mechanical stress [9]. Different configurations of ultrasonic equipment can be used for residual stress measurements. In each case, waves are launched by a transmitting transducer, they propagate through a region of the material and are detected by a receiving transducer, as shown in Figure 4. The technique when the same transducer is used for excitation and receiving of ultrasonic waves is often called the pulse-echo method (Fig. 4a). This method is effective for the analysis of residual stresses in the interior of a material. In this case, the averaged through thickness RS is measured. In the configuration shown in Figure 4c, the residual stress in a surface/subsurface layer is determined [9].

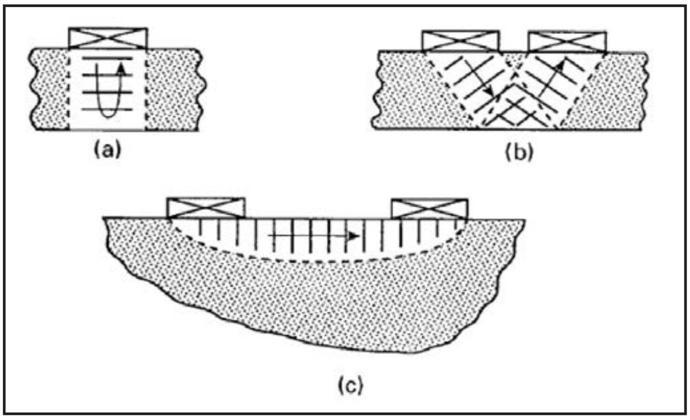

Fig. 4. Schematic view of ultrasonic measurement configurations: (a) through-thickness pulse-echo, (b) through-thickness pitch-catch and (c) surface pitch-catch [9]

In conclusion we can say that there are complex methods that can prevent dangerous SCC during operation of ammonia tanks and ensure their long-term operability and safety.

References

[1] Plagakis S.: *Is Anhydrous Ammonia a Risk to Your Community? – Center for Effective Government*

[2] Det Norske Veritas – Report No: 98-3111, rev.01 – 15.19 *Ammonia stress corrosion cracking*

[3] No.33 (1992) *Guidelines for the Construction of Pressure Vessel Type Tanks Intended for the Transportation of Anhydrous Ammonia at Ambient Temperatures*

[4] Nyborg R., Lunde L.: *Stress Corrosion Cracking in Anhydrous Ammonia Storage Tanks*. AIChE Ammonia Safety Symposium. Vancouver, 1994

[5] Syed Askari Raza Baqar, Yugal Raj Jain, Pradeep Khanna: *Vibratory Stress Relief Techniques: A Review of Present Trends and Future Prospects*. International Journal of Emerging Technology and Advanced Engineering, Volume 4, Issue 11, November 2014

[6] Kudryavtsev Y., Kleiman J.: *Fatigue Improvement of Welded Elements and Structures*

by Ultrasonic Peening. Proceedings of the ASME 2013 Pressure Vessels and Piping Conference PVP2013 July 14-18, 2013, Paris, France
http://dx.doi.org/10.1115/pvp2013-97185

[7] Kudryavtsev Y., Kleiman J.: *Fatigue Improvement of Welded Elements and Structures by Ultrasonic Impact Treatment (UIT/UP)*. International Institute of Welding. IIW Document XIII-2276-09. 2009

[8] Alghamdi T., Liu S.: *Low Transformation Temperature (LTT) Welding Consumables for Residual Stress Management: Consumables Development and Testing Qualification*. Welding Journal, July 2014, vol. 93

[9] Kudryavtsev Y.: *Ultrasonic Measurement of Residual Stresses in Welded Specimens and Structures*. Proceedings of the ASME 2013 Pressure Vessels and Piping Conference PVP2013 July 14-18, 2013, Paris, France
http://dx.doi.org/10.1115/pvp2013-97184