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MANUFACTURING AND INTEGRITY OF AMMONIA STORAGE TANKS

IZRADA I INTEGRITET REZERVOARA ZA SKLADIŠTENJA AMONIJAKA

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- ammonia tank
- P355NL2
- welding
- EN 14620
- structural integrity

Abstract

Manufacturing ammonia storage tanks represents a very demanding and responsible task. The paper presents the methodology for manufacturing two ammonia storage tanks in Russia, along with all the necessary steps. The base material used for tank manufacture is steel P355NL2. Instructions and requirements in EN 14620 standard need to be followed. This standard dictates all previously mentioned steps, hence the standard itself is shown here. The welding technology of two steel tank shells is also shown. Integrity assessment of the tanks is necessary to carry out immediately before the tanks are put into service. NDT results for welded joints and results of adequate tests performed on the tanks themselves provided insight into the quality of the performed work, and have shown that the selected welding technologies have met all requirements in terms of strength, thus confirming that the tank integrity is satisfactory.

Ključne reči
- rezervoar za amonijak
- P355NL2
- zavarivanje
- EN 14620
- Integritet konstrukcije

Izvod

Izrada rezervoara za skladištenje amonijaka predstavlja vrlo zahtevan i odgovaran posao. U ovom radu je prikazana metodologija izrade dva rezervoara za skladištenje amonijaka u Rusiji i koraci koji su pratili samu izradu. Osnovni materijal rezervoara je P355NL2. Neophodno je bilo praćenje uputstava i zahteva standarda iz EN 14620, koji je diktirao sve prethodno pomenute korake, pa je i sam standard predstavljen u radu. Detaljan prikaz tehnologije zavarivanja dva čelična omotača je takođe dat u radu. Integritet ovih rezervoara je neophodno proveriti pre neposrednog puštanja u eksploataciju. Rezultati ispitivanja zavarenih spojeva NDT metodama i odgovarajuća ispitivanja samih rezervoara pružili su uvid u kvalitet izvedenih radova i pokazali su da su tehnologije zavarivanja ispunile sve zahteve sa aspekta čvrstoće, a samim tim i integriteta rezervoara, koji je zadovoljavajući.

INTRODUCTION

Storing of ammonia typically requires special conditions, such as high pressure vessels or low temperature refrigerated vessels, due to its physical properties. In the case of large volumes of ammonia being stored in such tanks, a number of challenges arise, related to health, safety and environmental protection. It is recommended to design ammonia storage tanks in accordance with relevant standards, e.g. API 620 R: Design and Construction of Large, Welded, Low-Pressure Storage Tanks /1/, EN 14620 /2-6/. Materials used for atmospheric ammonia tanks need to be selected in accordance with the design code requirements. It is common practice to use carbon manganese steels for lower temperatures, with guaranteed toughness at -40 °C. These materials are also characterised by increased vulnerability to corrosion cracking with increased yield stress. For this reason, materials with yield stress ranging from 290 and 360 MPa are recommended for ammonia storage tanks /7-8/. In the case of new tanks, lower values in the aforementioned yield stress range should be used. Another important factor to consider is the compatibility between the yield stress levels of the parent material and the weld metal. Typically, filler material mechanical properties are slightly higher than that of the parent material, to ensure that failure does not happen within the welded joint itself. In the case of ammonia storage tanks, this compatibility is also important for resistance against stress corrosion cracking, caused by ammonia or any other working fluids, /9-10/.

In this paper is described the Kingisepp ammonia production plant which is located about 130 kilometres from St. Petersburg and is executed for EuroChem, one of the most important producers of fertilizers in the world. With a production capacity of 2700 tons per day, the plant is one of the most important in the European area. The manufacturing of two ammonia storage tanks is shown in the following section of the paper (Fig. 1). Both tanks are made of double steel walls, i.e. two steel mantles, 1 m apart from each other, with an additional concrete mantle around them. The structure of these two tanks allows them to work at temperatures ranging from -36 °C to 39 °C. Working pressure of the tank is 12 kPa, and its outer diameter is D_o = 45.5 m, whereas its inner diameter is D_i = 43.5 mm. Storage volume of both tanks is 45 000 cubic meters, whereas the total volume is 53 490 m^3. Outer tank height is H_s = 33.8 m, and inner tank height is 32 m. One tank weighs 1841 metric tons. These tanks are manufactured in accordance with the parts of standard EN 14620 which is described in the following sections. All activities from the start to the end of manufacturing, along with tests performed before placing the tanks into exploitation are done in detail. Both steel tanks are made by Tankmont company, /12/.

Figure 1. The Kingisepp plant; appearance of two ammonia storage tanks with double walls.

AMMONIA STORAGE TANKS AND EN 14620

According to EN 14620, which contains 5 parts, every storage tank (including the one here) consists of an inner steel container and a concrete outer container, /11/. Part 1 in /2, 7/ defines general requirements regarding the conception and selection of the tank types and general criteria of the performance, /2/. This standard is restricted to primary containers made of steel, and explicitly excludes inner containers made from pre-stressed concrete, /7, 11/. Part 2 of this standard, /3/, specifies the general requirements relevant to the materials, fabrications, welding methods, welding, construction and installation of all components for tanks. The types of steel required are defined depending on the liquefied gas to be stored, and hence the respective temperature and tank type, /11/. The permissible stresses in the plates and weld seams during normal operation and testing are defined, and the minimal thickness of the metal shell (e.g. 40 mm for butane and propane; 50 mm for ethane and LNG tanks). Part 2 also includes information about the design and calculation, fabrication and welding. Part 3, /4/, describes principles and details for the design and construction for concrete components, i.e. concrete outer container. Part 4, /5/, contains details of the design requirements for and selection of insulating materials, design of the vapour barrier against the infiltration of water vapour from outside and the vapour of the stored product from the inside, the design of the insulation system, other installations, commissioning and maintenance, /7, 11/. Part 5, /6/, defines the requirements regarding testing, drying, purging and cool-down of tanks.

WELDING TECHNOLOGY

In accordance with normative and standard, /13/, the inner course wall base material for both tanks is steel P355NL2. This is a normalized high-strength low-alloyed steel, meant for exploitation at lower temperatures and is typically used for pressure vessels and pipelines, due to its increased strength. Chemical composition of this steel is shown in Table 1, whereas its mechanical properties are given in Table 2.

Table 1. Chemical composition of P355NL2, /14/.

Element	C	Si_{max}	Mn	P_{max}	S_{max}	Al_{max}	Cr
%	0.18	0.50	11-1.7	0.025	0.005	0.020	0.30
Element	Ni	Mo	Cu	Ti	Nb	V	N
%	0.50	0.08	0.30	0.03	0.05	0.10	0.012

Table 2. Mechanical properties of P355NL2, /14/.

Tensile strength R_m (MPa)	Elongation A (%)	Yield stress $R_{p0.2}$ (MPa)
490-630	≥ 22	≥ 355

Reservoir shell of is made of two walls, 1 m apart from each other. Between the inner and outer reservoir there is an intermediate space called annular space that has several functions: for noticing any leakage of the inner tank, and as a thermal insulation since ammonia is stored at -40 °C and oxygen squeezed (nitrogen filled).

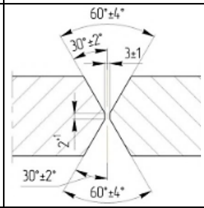
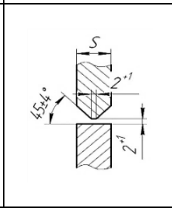
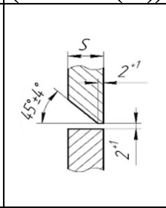
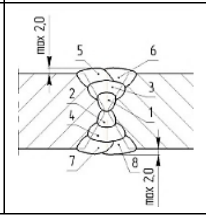
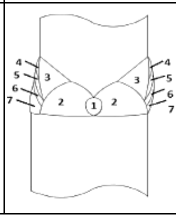
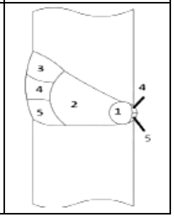
The first (inner) course is made of 14 sheet courses, whereas the second one (outer course) is made of 15 courses. Sheet thickness varies from belt to belt and is given in Table 3. Each belt consists of an average of 12 sheets, hence one level is made of 12 vertical welds and a horizontal one, divided into 12 zones, as seen in Fig. 2. During the installation of sheets, welded joint locations are horizontally shifted in order to avoid the forming of cruciform welded joints and mantle deformation. Standard sheet dimensions are 2320 × 6020 mm, with various thickness. Grooves are made by grinding, and Table 4 shows these grooves for vertical and horizontal joints for both mantles. Groove geometry depends on sheet and belt thickness. In addition, the welding plans for groove fillings are shown.

Table 3. Sheet thickness (in mm) for each course, first (inner) and second (outer) course.

First (inner) course	1. course	26.0
Second (outer) course		25.0
First (inner) course	2. course	24.0
Second (outer) course		22.0
First (inner) course	3. course	22.0
Second (outer) course		20.0
First (inner) course	4. course	20.0
Second (outer) mantle		18.0
First (inner) course	5. course	19.0
Second (outer) course		16.0
First (inner) course	6. course	17.0
Second (outer) course		15.0
First (inner) course	7. course	15.0
Second (outer) course		13.0
First (inner) course	8. course	14.0
Second (outer) course		13.0
First (inner) course	9. course	12.0
Second (outer) course		12.0
First (inner) course	10. course	12.0
Second (outer) course		12.0
First (inner) course	11. course	12.0
Second (outer) course		12.0
First (inner) course	12. course	12.0
Second (outer) course		12.0
First (inner) course	13. course	12.0
Second (outer) course		12.0
First (inner) course	14. course	32.0
Second (outer) course		12.0
First (inner) course	15. course	/
Second (outer) course		32.0

Figure 2. Appearance of the first (inner) mantle on one of the tanks, during manufacture.

Table 4. Vertical and horizontal groove geometry for both mantles on both tanks, including the welding plans.

	Vertical welds	Horizontal welds (belts 1-7)	Horizontal welds (belts 8-14(15))
Groove geometry			
Welding plan			

All vertical welds are made using electrode OK73.68 by manual arc welding procedure (procedure denoted by 111), and its welding parameters are given in Table 5. Horizontal welds are made in the following way:

– root pass is made using self-shielded flux-cored arc welding procedure (denoted by 114), and its corresponding welding parameters are shown in Table 6. The wire Fabshield Offshore 71Ni, manufactured by Hobart is used as filler material;

– filler and final passes are done using submerged arc welding (denoted by 121), and its welding parameters are given in Table 7. Additional materials used include the ESAB wire, along with OK Autrod 13.27 powder and OK flux 10.62 powder. Powder ESAB OK flux 10.62 is an agglomerated highly basic powder with low hydrogen content, used in submerged arc welding of pipelines, pressure vessels, as well as in shipbuilding and offshore structures, /15/.

The chemical composition and mechanical properties of used filler materials are given in Tables 8 and 9, /15,16/. All filler materials are chosen in accordance with standard normative and requirements, /17/, whereas the welder qualification is selected in accordance with /18/.

Table 5. Manual arc welding parameters of vertical welded joints.

	Current [A]	Voltage [V]	Welding speed [cm/min]	Wire diameter [mm]	Polarity	Heat input [kJ/mm]
Root pass	70-90	21-23	4.1-4.3	2.6	positive electrode	1.7-1.9
Filler pass	90-130	21-23	7.2-7.4	3.2	positive electrode	1.2-1.6
Final pass	90-130	24-40	8-8.2	4.0	positive electrode	1.2-1.7

Table 6. Root pass welding parameters by 114 procedure (horizontal joints).

Current [A]	Voltage [V]	Welding speed [mm/s]	Welding procedure
180-240	23-27	7-12	114

Table 7. SAW procedure welding parameters for horizontal joints.

Sheet thickness [mm]	Groove type	Number of passes	Current [A]	Voltage [V]	Welding speed [mm/s]
26	K	4 filler 8 final	340-420	25-28	14-20
24	K	4 filler 8 final	340-420	25-28	14-20
22	K	4 filler 8 final	340-420	25-28	14-20
20	K	4 filler 8 final	340-420	25-28	14-20
18	K	2 filler 6 final	340-420	25-28	14-20
16	K	2 filler 6 final	340-420	25-28	14-20
14	K	2 filler 6 final	340-420	25-28	14-20
12	half V	1 filler 5 final	340-420	25-28	14-20

Table 8. Chemical composition of used electrodes, /15, 16/.

Electr.	C	Si	Mn	P	S	Cr	Mo	Ni	V	Nb	Cu	Al
OK73.68	0.1	0.55	1.15	0.02	0.02	0.1	0.05	2.6	0.03	0.02	0.1	/
Fabshield Offshore 71Ni	0.05	0.004	1.21	0.011	0.03	0.2	0.01	0.85	0.004	/	/	0.9
OK Autrod 13.27	/	0.14	1.02	/	/	/	/	2.19	/	/	/	/

Table 9. Typical mechanical properties of weld metal obtained by OK 73.68 electrode, /15, 16/.

Electrode	Yield stress σ_t [MPa]	Tensile strength σ_m [MPa]	Elongation at 50 mm [%]
OK73.68	460	615	28
Fabshield Offshore 71Ni	422	533	30

Base material preheating temperature was 50-80 °C, even though environmental temperature was 20 °C, hence there was no real need for it. Supporting welds were made by spot welding, with lengths of 150-200 mm, at a distance of 100 mm apart. These spot welds were also a part of the welded joint. Indirect polarity (positive electrode) was used. Welding was performed alternatively, with the root- and one filler pass on one side, followed by a pass on the other side, in order to avoid deformations. Cleaning is performed by machine grinding, before and after the welding process. The welding technique used was upwards vertical, due to deformation. Sheets in each belt are displaced relative to the belt below, in order to reduce welding deformation (Fig. 2). In addition, U profiles are used to straighten deformed sheets and belts, due to heat input (Fig. 2).

The minimum number of welding passes for: 12 mm sheets is two; 12-17 mm thickness the minimum is four; 17-24 mm - six passes; and for 26 mm sheets, this minimum is eight passes. The number of passes also varied depending on the welder's technique. Figure 3 shows the roof in prefabrication and installation.

Figure 3. Sheet prefabrication and roof installation on a tank.

WELDED JOINT TESTING

After the completion of welding activities and the tanks are made, both vertical and horizontal welded joints are inspected and tested on both tanks and their mantles. Welded joint quality level is determined in accordance with EN ISO 5817, /19/. Visual inspection of welded joints is done with a 100 % scope, followed by penetrant testing, also done with a scope of 100 %. Level of acceptability of defects detected using the visual method was also determined based on /19/, whereas the level of acceptability for the penetrant test method was determined according to /20/. Ultrasound tests were also performed for all welded joints with a scope of 100 % for both tanks and their mantles in accordance with the corresponding standard, /21/. During ultrasound tests, a number of defects are observed in certain welded joints, and these welded joints are repaired. Repair welding on defect locations involved the removal of previous welds (so-called digging), as well as grinding and repair welding. After this, the repaired locations are tested once again, and no defects are detected. Hardness tests are also performed on welded joints after the welding and after repair welding. The hardness value had to be below 250 HB, because of the possibility of cold cracking in the welded joints.

INTEGRITY ASSESSMENT AND PERFORMED TESTS

After welding activities are completed and both (inner and outer) mantles are produced and the welded joints are tested, as described in the previous section, the integrity of both tanks is assessed. The following tests are performed in order to assess the tanks' safety before placing them into service, in accordance with the standard, /6/:
- geodetic control of soil settlement,
- hydrotesting of tanks,
- pneumatic and vacuum testing of tanks.

Geodetic control of foundation settlement is done according to the diagram shown in Fig. 4. The tank floor settlement is measured before and after the hydrotest. Geodetic control of soil settlement has shown satisfying results. After this, a hydrotest is performed according to the plan on Fig. 5, including filling the tank with water, followed by a break, and then emptying it. Water filling rate was 200 mm/hour, and water levels are measured every 60 minutes. Necessary water level was 29.4 m. Hydrotests also had satisfying results, and it is concluded that pneumatic and vacuum testing could be undertaken as well. The plan for pneumatic testing is shown in Fig. 6.

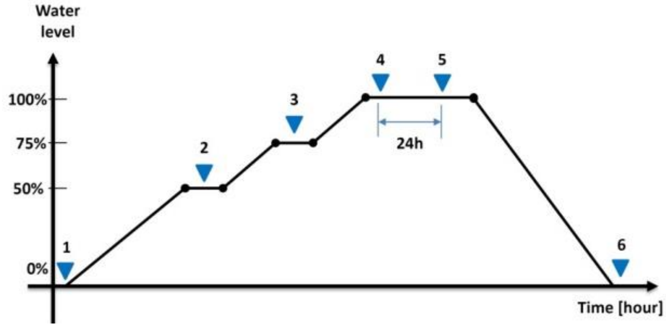


Figure 4. Plan for filling tanks with water and maintaining its level in order to perform geodetic control of soil settlement.

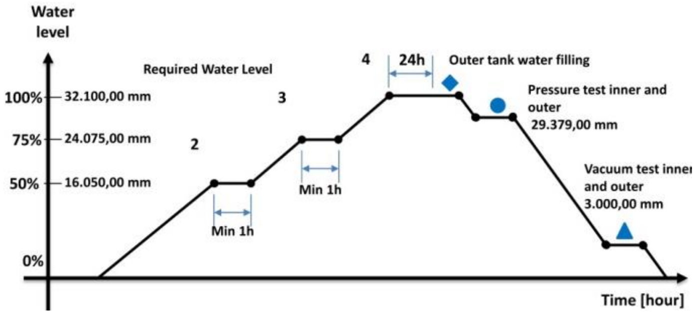


Figure 5. Plan for filling tanks with water and maintaining its level in order to perform the hydrotest.

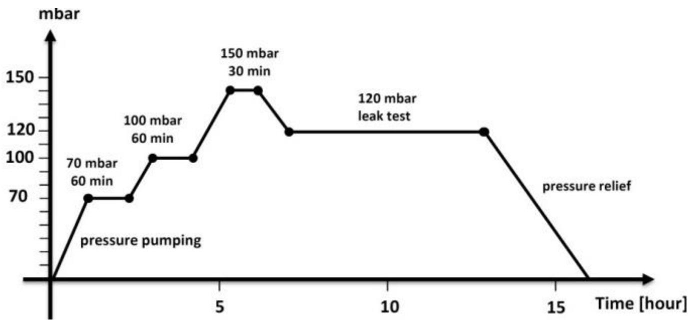


Figure 6. Pneumatic test plan.

The appearance of the installation in the pneumatic test is shown in Fig. 7. The necessary water level was 29.4 m. Pneumatic test stages are given in chronological order as follows:
- sealing of all openings in the inner mantle,
- attachment of hose and connectors as shown in the sketch,
- pouring of water into the safety valve for pneumatic testing,
- closing of the release valve at K4,
- opening of the manual valve at K1,
- starting the compressor,
- opening of the compressor valve,
- achieving 150 mbar pressure in 6 h (with stops at 70 and 100 mbar), followed by simultaneous closing of the manual valve at K1 and the compressor,
- opening of the release valve at K4 up to 120 mbar,
- leak test of welded joints,
- after this check, air is released via valve K4,
- opening of the inner mantle valve,
- inner mantle testing is finished,
- closing of the outer mantle opening and repeating the previous steps in order to test the inner mantle,
- outer mantle testing is finished.

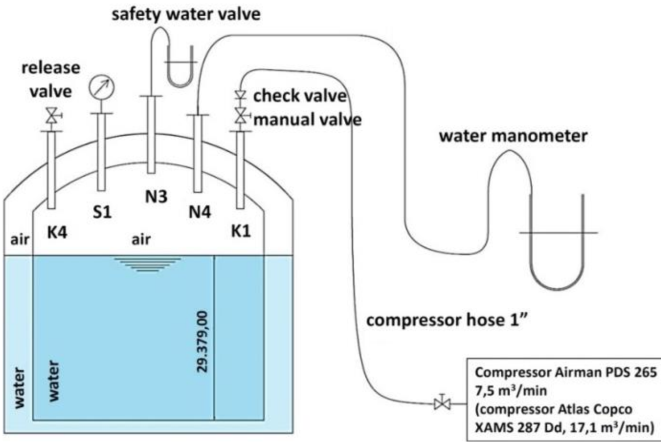


Figure 7. Pneumatic test installation for a pressure of 150 mbar.

After the pneumatic tests, water is released up to level of 3 m, and the vacuum test is performed in accordance with the plan shown in Fig. 8. The appearance of the vacuum test installation is shown in Fig. 9. The stages of these tests, performed at -5 mbar, are shown below, chronologically:
- sealing of all but one opening on the outer mantle,
- connecting the hose to the water discharge,
- pouring water into the safety valve and the water manometer for the purpose of vacuum testing,
- closing of release valve at K4,
- closing of manual valve at K1,
- opening of release valve in order to slowly release the water from the outer into the inner mantle, which marks the beginning of the test,
- monitoring the manometers until a magnitude of -5 mbar,
- closing of the release valve and opening of the manual valve at K1 and K4,
- opening of the outer mantle valve,
- outer mantle testing is finished, remaining water is taken into the inner mantle,

– sealing of all but one opening at the inner mantle,
– repeating of the steps as in the case of the outer mantle,
– opening of the release valve in order to release the water from the inner into the outer valve,
– monitoring of the manometers until -5 mbar,
– closing of release valve and opening of the manual valve at K1 and K4,
– opening of the inner mantle valve,
– vacuum testing of the inner mantle is finished,
– emptying of the inner and outer tank mantles.

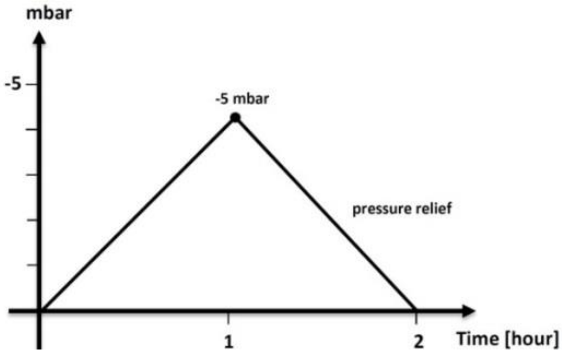


Figure 8. Vacuum test plan

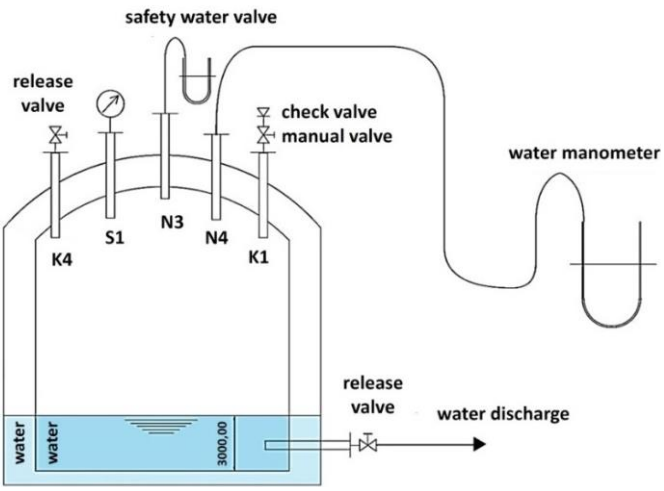


Figure 9. Vacuum test installation for -5 mbar.

DISCUSSION AND CONCLUSIONS

Manufacture of both ammonia storage tanks required the application of EN 14620 and other relevant standards which are related to welding technology qualification, welder attests, material selection, etc., i.e. all activities performed during the welding and installation of the tanks, as well as putting them to work. Particular attention is devoted to welding activities, defining the welding technology and welded joint testing. In defining the welding technologies and filler material selection, the base material of both mantles on both tanks is taken into account, including its welding specifics. Each step in the installation of these tanks is supervised. Adequate staff expertise, from engineers to welders and NDT testers, represents a specific aspect needed in order to successfully complete a project such as this one.

During the installation of each belt, it was necessary to check global and local deformations in each belt for both mantles on both tanks. For the purpose of decreasing the potentially considerable deformation of belts, their welded joints are displaced relative to each other. The allowed deformation is defined in accordance with relevant standards, depending on material thickness. Deformation is monitored before the welding and after installation, and also during the welding process itself. Mantle deformation is monitored using geodetic equipment.

Careful monitoring of each step during the tank construction itself is insufficient for positive safety and integrity assessments. Test results for all welds, obtained by NDT methods (visual, penetrant and ultrasonic) had revealed defects in certain welded joints, which are repaired, and no additional defects are detected once the repeated welded joint tests are completed. This was followed by geodetic control of soil settlement, hydrotesting and pneumatic and vacuum testing of the tanks, and the results of these tests provided a more complete insight into the integrity of both tanks, prior to placing them into service. During these tests, there were no signs of leakage, and the tanks are put into exploitation. The tanks are in exploitation for over a year and are being monitored.

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REFERENCES

1. API STD 620: Design and Construction of Large, Welded, Low-pressure Storage Tanks
2. EN 14620-1:2008: Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C - Part 1: General
3. EN 14620-2:2008: Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C - Part 2: Metallic components
4. EN 14620-3:2008: Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C - Part 3: Concrete components
5. EN 14620-4:2008: Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C - Part 4: Insulation components
6. EN 14620-5:2008: Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C - Part 5: Testing, drying, purging and cool-down
7. Guidance for Inspection of Atmospheric, Refrigerated Ammonia Storage Tanks, Copyright 2008 EFMA
8. EN-13445-2:2015: Unfired pressure vessels - Part 2: Materials
9. Beloev, M., Lolov, N. (2016), *Some technological features of welding while building of the ammonia tanks*, Biuletyn Instytutu Spawalnictwa, 5/2016: 104-110, ISSN 2300-1674.
10. Frank Cheng, Y., Stress Corrosion Cracking of Pipelines, John Wiley & Sons, 2013. doi: 10.1002/9781118537022
11. Rötzer, J.: Design and Construction of LNG Storage Tanks, Ernst & Sohn (a Wiley Brand), 2019.

12. www.tankmont.rs
13. EN 10028-3:2017: Flat products made of steels for pressure purposes - Part 3: Weldable fine grain steels, normalized
14. Total materia - totalmateria.com
15. ESAB - www.esab.com
16. Hobart filler metals - dev.hobartbrothers.com
17. EN ISO 26304:2017: Welding consumables - Solid wire electrodes, tubular cored electrodes and electrode-flux combinations for submerged arc welding of high strength steels - Classification
18. SRPS EN ISO 9606-1:2017: Kvalifikaciono ispitivanje zavarivača – Zavarivanje topljenjem – Deo 1: Čelici
19. EN ISO 5817: Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) - Quality levels for imperfections (ISO 5817:2014)
20. EN ISO 23277:2015: Non-destructive testing of welds - Penetrant testing - Acceptance levels (ISO 23277:2015)
21. EN ISO 11666:2012: Non-destructive testing of welds - Ultrasonic testing - Acceptance levels

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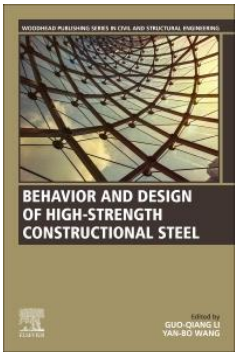

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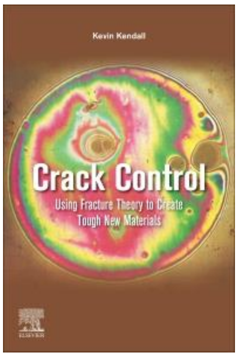

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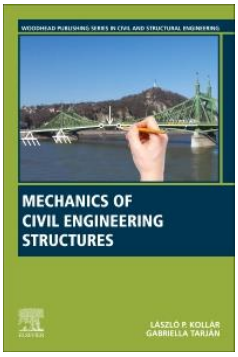

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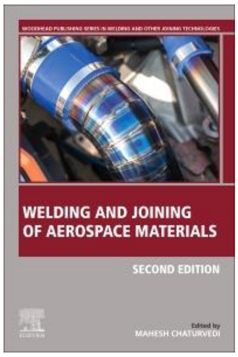

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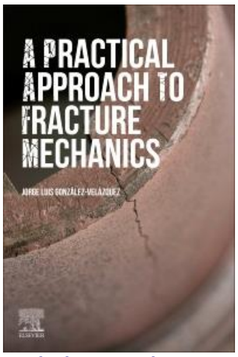

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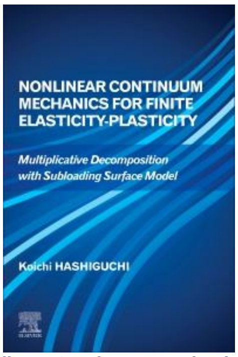

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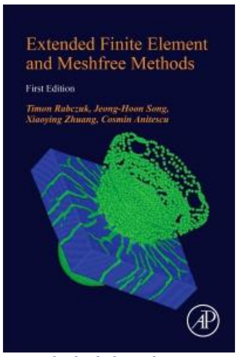

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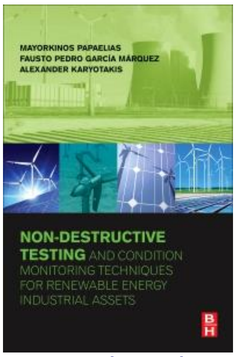

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