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Solutions and Procedures for Repairing a Damaged Vertical Cylindrical Tank – Depositor

Elisaveta Doncheva[a], Viktor Gochev[b], Aleksandra Krstevska[a],*

[a]*Department of Welding and Welded Structures, Faculty of Mechanical Engineering, Skopje, Republic of N. Macedonia*
[b]*AL-VI Inspekt, Veles, Republic of N. Macedonia*

Abstract

This research paper describes and evaluates the options for repairing and rehabilitating a damaged vertical cylindrical tank (depositor). The vertical cylindrical tank is part of a wastewater treatment plant located in the vicinity of a metallurgical plant for the production of ferrosilicon Jugohrom Alzar LTD, and its components, shell, and floor are severely damaged as a result of the tank's long-term exploitation and improper maintenance. The tank is used in a wastewater treatment plant station to reduce and neutralize the carcinogen hexavalent chromium (Cr VI) into Cr-III. Two repair techniques are analyzed and investigated. The first is to repair the damage by restoring the required projected thickness of the sheet metal walls through repair welding. The other method is to apply liquid metals to the damaged areas to achieve the required projected thickness of the materials of the individual components. Mechanical tests are required regardless of which of the two repair methods is used. In order to obtain a more realistic picture of the influence of the weld, respectively of the liquid metal, samples were made according to the tensile test standard, ISO 6892-1, on which damages similar to those found on the tank were done. The obtained experimental results, along with the discussions for future research possibilities, contribute to upgrading and enhancing current knowledge in the direction of finding the most appropriate way to repair the damage that occurs in vertical cylindrical tanks as a result of their long-term exploitation.

Keywords: vertical cylindrical tank; damage; welding; advanced materials

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* Corresponding author. Tel.: /; fax: /.
E-mail address: aleksandra.krstevska@mf.edu.mk

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1. Introduction

Modern industrial development requires large storage spaces for a diverse range of materials, including water, oil and oil derivatives, acids and other liquids, and liquefied gases. The most common structures with internal cavities used for storage, chemical technological processes, and transportation of gas, liquid, and other materials are cylindrical tanks (Adziev, 1995). The tanks are classified into fixed-roof tanks and floating-roof tanks (Wit, 1973). The welded vertical cylindrical tank, which many countries use with capacities of up to 200,000 m^3, is the most cost-effective storage solution. In any case, welded tanks are often damaged and require repair, as shown in couple of recent papers (Jovicic et al, 2020, Jeremic et al, 2021). Therefore, tanks should be built and operated using appropriate scientific, technologically feasible, and economically rationalized solutions; thus, a greater emphasis should be placed on establishing a scientific foundation to assess the strength, stability, resilience, maintenance, and reparation of vertical cylindrical tanks under real-world operating conditions (Suleimenov at al. 2022, Jaric et al, 2023, Jovanovic et al, 2022, Jeremic et al, 2020, Milovanovic, 2021, Tanaskovic et al, 2021). The industrial sector uses an average of 22% of total wastewater produced globally, and approximately 80% of total wastewater produced is discharged into water channels, causing pollution, and endangering human health and marine life (Dutta et al. 2021). In this study, we are looking into repair options for a 550 m^3 vertical cylindrical tank/depositor that was built as part of the wastewater purification station at the metallurgical plant for ferrosilicon production "YUGOHROM ALZAR" in the village Jegunovce, municipality of Jegunovce, Tetovo.

The purpose of this water waste treatment plant is to treat all types of wastewaters occupied by the landfill, which is near the village of Jegunovce, and it was created from the waste that has been thrown out of the Plant for many years. An even bigger problem is also created by the fact that the Muzga stream passes under the landfill itself and it is a tributary of the river Vardar, which is highly polluted. In addition, there is a great possibility of polluting Rashce which is the main supplier of water for the city of Skopje. To avoid this situation, a system was developed for capturing wastewater from the landfill and returning it to natural water streams after treatment and using reduction and neutralization procedures. Before returning the captured and treated water from the landfill to the natural water flows, they are brought into a vertical cylindrical tank – depositor so that the solid components from the reduction and neutralization process are deposited on the bottom of the tank, and the rest of the liquid that is purified is discharged into the natural water streams near the treatment station. The treatment plant's main task is to convert hexavalent chromium Cr (VI) from the affected waters from the landfill into trivalent chromium Cr (III), which reduces the concentration of Cr(VI) in the treated liquid by at least about 1200 times, that is, at the entrance to the treatment plant, the concentration of Cr(VI) in the affected liquid is from 60 mg/l to 120 mg/l, while in the outlet waters, after the purification process, the concentration is 0.05 mg/l. The deposited components of the treated water are not removed from the treatment plant at the current time of operation and are deposited from the bottom to the upper parts of the settling tank. As a result, there is an excessive amount of residual sediment inside the settling tank, causing local leakage of contents from within the depositor through its bottom, as well as severe deformation on the shell of the depositor, which is part of the treatment plant's equipment. According to private communication (2002), the technological scheme of the system and the depositor is shown in Fig 1.

The investigation was performed on prepared tensile specimens according to EN ISO 6892-1:2009 (2009) with two different types of defects and analyzed the mechanical properties of the specimens. Tensile tests at ambient temperature were determined using the following equipment static tensile test – SHIMADZU tensile testing machine and analyzed the results. According to the results is made a conclusion which repairing method to be used for the repair of the depositor.

1. Problem definition

The paper describes and evaluates repair and rehabilitation options for a damaged vertical cylindrical tank (depositor). The vertical cylindrical tank is part of a wastewater treatment plant located in the metallurgical plant for the production of ferrosilicon. The wastewater treatment plant station is used to reduce and neutralize the carcinogen hexavalent chromium (Cr VI) into Cr-III (three valent chromium), and its components, shell, and floor are severely damaged because of the tank's long-term exploitation and poor maintenance. Fig. 2 shows a view of both sides of the tank.

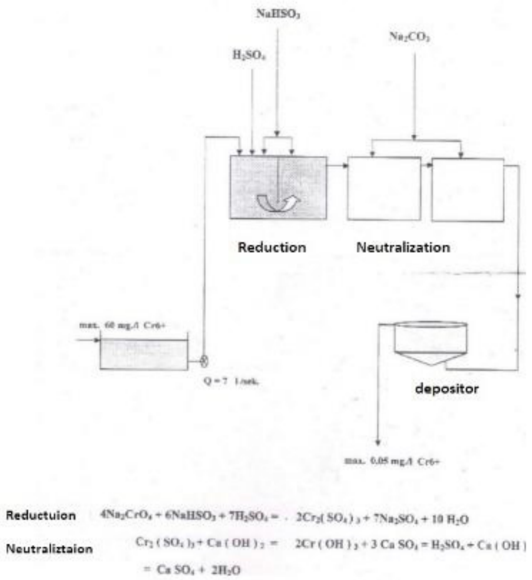

Fig.1 Technological scheme of the wastewater treatment plant

Fig. 2. The tank with a view of both sides

At the current operation of the treatment plant, the solid components are not removed, and they are deposited from the bottom to the upper parts of the vertical tank. The tank is designed for working fluid water with a low concentration of sediment with a specific weight of 1kg/dm^3 (Cubic Decimeters), and the condition found is 2.7 times greater, specific mass of sediment in the depositor, that is, a fluid with 2.72kg/dm^3 (Cubic Decimeters).

Because of the excessive amount of residual sediment inside the depositor (fig.3) there is a:

1. Local leakage of the content from inside the depositor through its bottom
2. Deformations of the cylindrical casing of the depositor

This paper aims to find the best solution for repairing the tank.

Fig. 3. Photo documentation of the current situation of the tank

2. Materials and methods for repair

The material from which the tank is made was determined according to a chemical analysis of a sample taken from the tank shell. According to the results obtained from the analysis, it was determined that it is structural steel S360 which can be seen in the table below according to the chemical analysis and EN 10025-2: 2004, 2004.

Table 1: Chemical composition of the material S360 ($\sigma_{p0,2} \geq 235$ MPa, 360 MPa $\leq \sigma_m \leq 500$ MPa, A ≥ 25 %

Specimen	**C**	**Si**	**Mn**	**N**	**S**	**P**	**Cr**	**Ni**	**Cu**	**Al**	**Fe**
1	0,125	0,21	0.42	0,077	0,029	0,015	0,02	0,07	0,15	0,006	98,9
2	0,124	0,22	0,43	0,008	0,028	0,015	0,02	0.07	0,14	0,006	98,9
S360											
Min			0,3								
Max	0,17	0,35	0,8		0,04	**0,04**					

The following methods are considered for the repair of the vertical cylindrical tank – depositor:

1. Repair welding at locations where the damage is present.
2. Addition of lost material by applying liquid composite metals (applying a multi-purpose machinable composite material Belzona 1111 – super metal)

The mechanical properties of the materials, as well as the proposed repair methods, are examined in this paper using tensile test experiments on specimens.

4. Experimental work

Samples were made according to the ISO 6892-1 tensile test standard, with damages similar to those found on the tank, to get a more realistic picture of the impact of the weld and liquid metal. To perceive the difference in the influence of the size of the damage on the strength characteristics, two types of samples were made, as shown in Fig. 4, one with damage length of 46 mm and depth of 3mm and the other with a damage length of 92 mm and depth of 3mm. The samples have a thickness of t=8mm. Table 2 shows the nomenclature of all test specimens classified according to the repair method.

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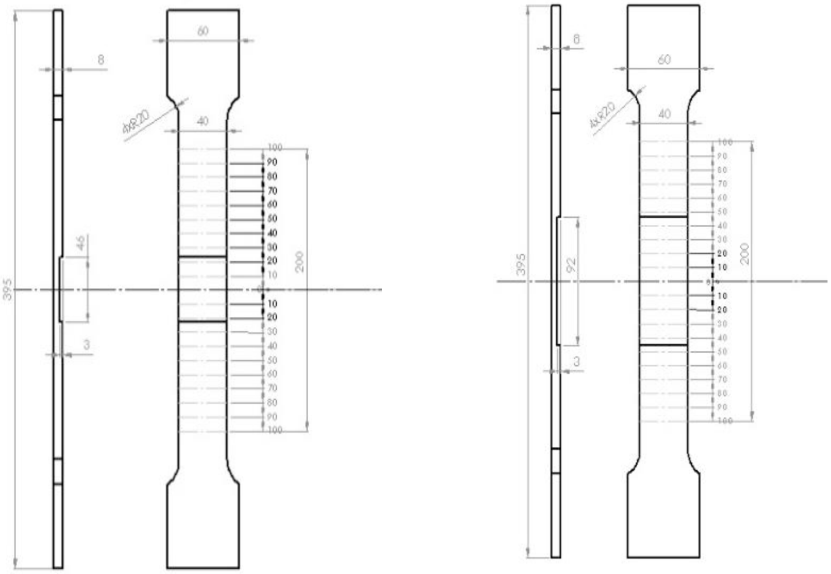

Fig.4: Sketch of the test samples that should be made for the experimental test

Table 2: Nomenclature of test specimens

Probe	**Dimensions of damage (mm)**	**Repair method**
Probe 1	92x3	Repair welding
Probe 2	92x3	Repair welding
Probe 3	46x3	Repair welding
Probe 4	46x3	Repair welding
Probe 5 (base material)	No	
Probe 6 (base material)	No	
Probe 7	46x3	Repair with liquid metal
Probe 8	46x3	Repair with liquid metal
Probe 9	92x3	Repair with liquid metal
Probe 10	92x3	Repair with liquid metal

Fig.5: Preparation of samples by repair welding

Fig.6: Preparation of samples by addition of liquid super metal, Belzona

Fig.7. a) Samples from base material without defects and without repair, as standards for comparing the results of the tensile test; b) Samples for tensile testing with the previously defined number of marks depending on the dimensions of the defect and the method of its repair

The process of preparing the specimens with the repair welding technique is shown on figure 5 and on figure 6 is shown the preparation of samples by adding an additional liquid super metal. The specimens 5 and 6 presented on figure 7 a) are made without defect to only compare the results of the tensile test as standards and all marked specimens with defined defects are presented on figure 7 b).

3. Analysis and discussion of the results

The dimensional characteristics of the test specimens after tensile testing are shown in table 3, and the strength characteristics of the tested sample, $\sigma p_{0.2}$, σ_m, and σ_u, are shown in table 4, depending on the degree of testing, i.e., whether the test was carried out until the moment of fracture or if it was stopped before the moment of fracture of some of the test samples.

Table 3: Dimensional characteristics of the test specimens after tensile testing

No.	**Mark up of pieces**	**Initial length. mm**	**Initial widht., mm**	**Initial thickness mm**	**Initial cross-section mm^2**	**Length of fracture**	**Wight after fracture**	**Thickness after fracture**	**Cross-section after fracture**	**Elongation %.**	**Contraction %**
1.	H92/1	200	36.5	7.8	284.7	230	29	5.65	163.85	15	42
2.	H92/2	200	33.6	7.75	260.4	224	30.3	6.55	198.47	12	24
3.	H46/1	200	36.9	7.5	276.7	232	28.7	5.3	152.11	16	45
4.	H46/2	200	36.7	7.35	269.7	229	30.2	5.48	165.5	15	39
5.	OM/1	200	39.95	8.05	321.6	248	30	5.65	169.5	24	47
6.	OM/2	200	40.2	8.05	323.6	246	32.5	5.65	183.6	23	43
7.	TM46/1	202.4	40.1	8	320.8	210	36.4	4.4	160.16	4	18
8.	TM46/2	203	40.1	8.05	322.8	213	35.6	4.4	156.6	5	23
9.	TM92/1	202.4	40.1	8	320.8	220	32.2	3.35	107.87	9	47
10.	TM92/2	202.4	40.1	8	320.8	217	35.7	4.1	146.37	7	26

NOTE: The test pieces with numbers 1, 3, and 5 were tested until fracture, while the others were stopped before fracture but with defined σk.

Table 4: Strength characteristics of the tested specimens, $\sigma_{p0.2}$, σ_m and σ_u

No.	**Mark up**	**Initial cross section mm^2**	**Fracture cross sec-tion mm^2**	**Yeld force. Fp$_{0,2}$, dN**	**Ultimate force, Fm, dN**	**Fracture force, Fu,dN**	**Yield strength $\sigma_{p0,2}$,N/mm^2**	**Ultimate strength σ_m, N/mm^2**	**Fracture strength σ_u, N/mm^2**	**Note**
1.	H92/1	284.7	163.85	10835	15280	13567	380.6	536.7	163.85	Fracture
2.	H92/2	260.4	198.47	10533	14224	-	404.5	546	198.47	No fracture
3.	H46/1	276.7	152.11	11069	15267	12962	400	551	152.11	Fracture
4.	H46/2	269.7	165.5	9174	12420	-	340	461	165.5	No fracture
5.	OM/1	321.6	169.5	14369	16319	13145	447	507.4	169.5	Fracture
6.	OM/2	323.6	183.6	14458	16380	-	447	506.2	183.6	No fracture
7.	TM46/1	320.8	160.16	7828	11274	9473	398	574	160.16	No fracture
8.	TM46/2	322.8	156.6		11959	-	-	591	156.6	No fracture
9.	TM92/1	320.8	107.87	8870	10500	8642	434	513.4	107.87	No fracture
10.	TM92/2	320.8	146.37	7880	11480	-	400	582	146.37	No fracture

After tensile test of specimens made with repair welding, shown in Figure 8 and the performance conditions of the specimens in this figure impose the question of analysing the reasons why the samples with a larger defect length fracture in the weld zone or opposite why the sample with a smaller defect dimension fractures in the base material.

On the other hand, the binding/adhesive force of the liquid metal with the base material separated in the elastic state of deformations for the base material, shown in Fig. 9. The measured lengths of the liquid metal after the test for both test (7 and 8) specimens are 46.66 mm. The plastic deformation of the liquid metal at the time of fracture from the base metal is 1.43% and the moment of fracture of the liquid metal from the base material was accompanied by a sound. The examination after fracture of the liquid metal from the base material has no special significance, at least at this point of examination.

Fig.8: Repair welding

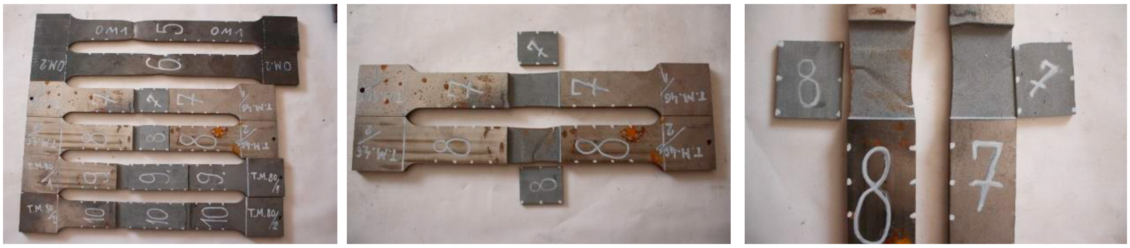

Fig.9: Repair with liquid metal

On fig.10 is presented a view of test specimens with a 92mm defect repaired by welding and liquid metal compared to samples form base material, left, and the same conditions for a 46mm defect, right.

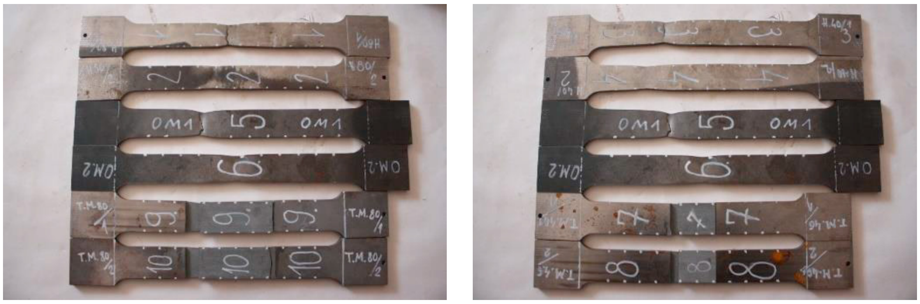

Fig.10: Test samples

The samples with repair welding show greater deformation characteristics than those repaired with liquid metal for both the 46 mm defect case and the 92 mm defect case. The performed repaired welding of the defect with a length of 92 mm yielded in the welded metal and the performed welding of the defect with a length of 46 mm yielded in the base metal. Samples with 92 mm repair welding have smaller ultimate deformations than those with 46 mm repair welding. Tests of base material without defects and without repairs fully confirmed the strength-deformation characteristics of S360.

Reparation with liquid metals with 46 and 92 mm separated from the base metal in the elastic state of deformations. The absolute elongation of the liquid metal with a length of 46 mm is 0.66 mm, i.e. 1.4%, and the absolute elongation of the liquid metal with a length of 92 mm is 0.1 mm, i.e. 0.1%. Test samples repaired with liquid metal with 46 mm have smaller ultimate deformations than those with 92 mm. Longer lengths of repair welding and repair with liquid metal give worse deformation characteristics during tensile testing.

4. Conclusion

In this paper are analysed the tensile characteristics of the material with two different repair techniques as methods for repair of cylindrical vertical tank/depositor. After the experimental part is concluded that the specimens with repair welding give better deformation characteristics than the specimens with liquid metal.

As consideration for further work is pointed out to monitor the deformation and behaviour of the liquid metal, with special measuring tapes placed on its surface. In the test with liquid metal repair, the test should be followed until the moment of separation of the liquid metal from the base material. Liquid metal repair would be used for stresses in the elastic region and the repair welding would be used in the elastoplastic region. In the analysis, the thickness of the layer applied by repair welding and repair with liquid metal should be included.

The experiment and its results, together with the open possibilities for future research, open the previous and further knowledge in the direction of finding the most appropriate way to repair the damage that occurs in the vertical cylindrical tank as a result of its long-term exploitation.

References

Adziev, T., Konstrucija i izrabotka na procesni aparati, Skopje 1995

de Wit, J., 11 - Steel vertical cylindrical storage tanks, Mechanical Engineer's Reference Book (Eleventh Edition), Butterworth-Heinemann, 1973, pp.11-2-11-14,

Suleimenov U. et al., Estimation of the Strength of Vertical Cylindrical Liquid Storage Tanks with Dents in the Wall, Eastern-European Journal of Enterprise Technologies, 1 (7 (115)), 6–20, 2022.

Deblina Dutta, Shashi Arya, Sunil Kumar, Industrial wastewater treatment: Current trends, bottlenecks, and best practices, Chemosphere, Volume 285,2021

Private communication with metallurgical plant, Jegunovce, R. Of N. Macedonia, 2020

European standard EN ISO 6892-1:2009, Metallic materials. Tensile testing. Part 1 – Method of test at room temperature. European Committee for Standardisation, 2009

European standard EN 10025-2: 2004 Hot rolled products of structural steels. Technical delivery conditions for non-alloy structural steels, 2004

Jarić, M., Budimir, N., Petronić, S., Maslarević, A., Jovanović, A., Oily-water tank operational reliability analysis in an oil and gas facility, Structural Integrity and Life, Vol. 23, No. 1, pp. 82-86, 2023

Jovanović, A., Đorđević, B., Jeremić, L., Milovanović, N., Smoljanić, T., Integrity assessment of autoclaves after reconstruction, Structural Integrity and Life, Vol. 22, No. 3, pp. 347-352, 2022

Jeremić, L., Sedmak, A., Milovanović, N., Milošević, N., Sedmak, S.A. (2021), Assessment of integrity of pressure vessels for compressed air, Structural Integrity and Life, 21(1): 3-6

Milovanović, A.M., Mijatović, T., Diković, L., et al. (2021), Structural integrity analysis of a cracked pressure vessel, Structural Integrity and Life, 21(3): 285-289

Jeremić, L., Đorđević, B., Šapić, I., et al. (2020), Manufacturing and integrity of ammonia storage tanks, Structural Integrity and Life, 20(2): 123-129.

Jovičić, R., Jeremić, L., Milošević, N., Sedmak, A., Milovanović, N. (2021), Repair welding of pressure equipment with unacceptable defects, Structural Integrity and Life, 21(2): 163-167

Tanasković, D., Petrović, S., Đorđević, B., et al. (2021), Algorithm for defining quality of base material for repair welding, Structural Integrity and Life, 21(3): 279-284.