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Mechanical Properties of the Assembly Welded Joint of the Oil Transportation Tank After a Long-Term Service

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Abstract. The paper provides results of studying a change in mechanical properties of the design elements metal and assembly welded joints of a vertical steel tank after a long-term service in oil transport facilities.

Introduction

The reliability of pipeline transport systems depends on the reliability of all the facilities involved in a technological process [1,2]. Tank batteries play an important role in maintaining uninterrupted oil transmission.

Existing tank batteries are significantly worn out. Recently, the amount of repair, reconstruction and construction of new tanks has increased dramatically. This has resulted in a sharp rise in technical diagnosing of vertical steel tanks (VST) using new technical means and techniques. To solve the problem of evaluating the technical state of vertical steel tanks a two-level technical diagnosis system has been implemented according to which the frequency and type of inspection depends on the operation life. However, the existing technical diagnosis system does not fully meet current requirements.

In such conditions, it is necessary to take actions to increase the efficiency of tank use by prolonging a safe tank operation life in production. As vertical steel tanks are elements of complex engineering systems of oil and oil products production, transportation and storage, providing safety and evaluating a safe operation life of in-service tanks are related to increasing the operation life of the tank battery and the entire pipeline transportation system. Moreover, increasing the tank reliability results in saving the main funds.

The problem of the tank safety is connected to the issues of reducing oil and oil product losses caused by spills and accidents, as well as a poor technical condition of the tank shell and bottom [2]. Financial losses caused by tank accidents are great and tend to become even greater as the tank capacity increases. Because of numerous related expenses, the real loss exceeds that of the reclamation and product cost. Expenditures on contamination control alone caused by spills are 4 times greater than direct losses.

When diagnosing the technical state of VSTs after a long service it is necessary to take into account the industry expertise in the complex tank inspection during which special attention must be paid to changes in the geometric shape that can occur under conditions of the trunk line tank battery operation.

Defects influencing the reliability of vertical steel tanks can be brought in to their construction at any stage of their life cycle: from design to operation. Conditionally, these defects of tank design elements can be divided into five groups depending on the period of their formation:

- metallurgical — brought in to the design during rolled product manufacturing (folds, delamination, non-uniform alloying, scuffing, micro cracks, distortion of the rolled product geometry, etc.);
- manufacturing — occurred during fabricating work pieces (defects of assembling and welding);
- transport — originated during transportation of metal structure elements to the assembly site (dents, scuffing, tearing, crumpling, bending, corrugation, etc.);
- assembly —imperfections during tank assembling (defects of bases and substructures, defects of assembling and welding of metal structures, angularity of welds, remains of fixtures, etc.);
- operational — occurred during tank operation (deposits, stability loss, corrosion, buckling, etc.).

As a rule, these defect groups are detected during technical diagnosis of tanks by means of non-destructive testing: visual, ultrasonic, radiographic, etc. Conducting inspection of VSTs used at oil pump stations of the oil trunk lines allows us to conclude that basic defects occurring practically in all VSTs and having an essential impact on their operational reliability are corrosion defects and tank geometry irregularities. It is due to the fact that these particular defects have a strongly pronounced operational character of development.

It is known that in the course of long-term service of metal tank structures there can be a change of properties of parent metal and weld metal of weld seams. It can lead to strength decrease, impact strength change and plasticity increase.

In [3] results of an experimental evaluation of properties of parent metal and tank welds metal after various service lifespans up to 25 years in the area of the Tuapse city are given. It has been established that a long-term service under the influence of media leads to strain ageing of the metal, i.e. decrease in resistance to brittle fracture. The coefficient of strain ageing for the investigated steels after 25 years of service equals 1.1÷1.34. Tests have shown that strength characteristics have small deviations from standard values, however, a considerable decrease in plasticity characteristics is observed. It has been found in this work that changes in mechanical characteristics of various zones of a welded joint during service of steel 09G2S showed the most intensive degradation processes occurring in a heat-affected zone: σ_y rises by 12-13 % after 20 years of service; plasticity characteristics decrease (ε by 25-30 %).

Thus, a change of mechanical properties of a metal can be referred to as an operational defect of vertical steel tanks. A current problem is researching into changes of mechanical properties of a welded assembly joint of an oil transportation tank after a long-term service, as a considerable impact of welding on metal properties is known [4].

The subject of research is a vertical steel tank RVS-20000 (a type design № 704-1-60, CNIIPSK of N.P. Melnikov, Moscow). The tank has been assembled and put into operation in 1988 at the oil pumping station. The construction region falls within the ID climatic region, the ambient temperature on the coldest days being -48 °C, the absolute minimum ambient temperature— -55 °C.

After the tank has been routinely taken out of service, a due full technical diagnosis has been performed to determine its condition, evaluate the possibility of further operation and necessity of repair. Having undergone the repair work, the tank has been tested by water loading and put into operation once again. After one year of service, on the sheet of the second belt of the VST wall a crack was formed.

Modern studies have shown that fatigue destruction occurs in structures with a large number of technological and operational defects, such as quenching cracks, welding defects, non-metallic inclusions, pores, pitting corrosion, nicks, undercuts, scratches, machine marks and others. VST cyclic loading leads to accumulation of damages starting from local plastic deformation causing shear bands and micro cracks, one of which and, in some cases, several of them evolve into a main crack resulting in the limit state — tank destruction.

According to the regulations on tank service at oil pumping stations the presence of cracks of any size in VST bearing elements is prohibited. It is connected with the possibility of brittle fracture of vertical steel tanks [5,6].

2. Methods and results

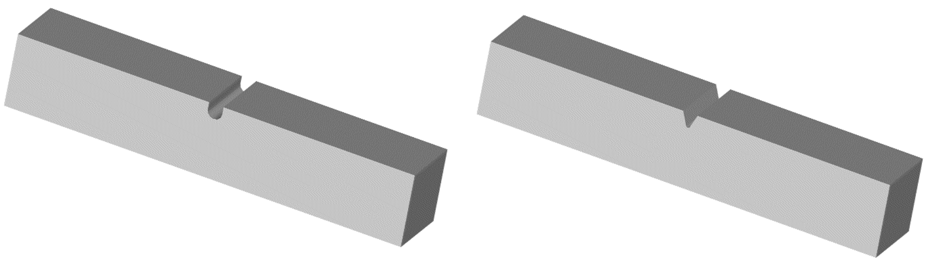
For the research, two fragments 750×750 mm in size have been cut out from the tank wall: one fragment with a crack – from the second belt, and another one, defect-free – from the first belt. Sampling of such fragments is due to the following reasons. The first and second belts of the wall are the most loaded elements of the tank design and they experience the greatest radial motion. Internal stresses in the metal of the first belt are greater than in the second one, as the height of the tank wall and the liquid acting on the first belt is greater than the height of the same parameters acting on the second belt. However, despite this fact, the crack was formed not in the first belt, but in the second one. Therefore, it has been decided to compare metal properties of the first and second belts.

As an assumption concerning the possible reasons of the crack origin in the second belt of the tank a hypothesis has been put forward that the material of the wall doesn't conform to the designed material. To prove this assumption the analysis of chemical composition has been carried out which showed that the material of the first and second belts by its elements content matches the steel grade 09G2S. The results of chemical analysis of the fragments material and the requirements of the standard documentation are given in table 1.

Table 1. Chemical composition of investigated steels.

Mass fraction of elements	Standard value for steel 09G2S (GOST 19281-89*)	Value for fragment of first tank ring	Value for fragment of second tank ring
Carbon [%]	Not greater than 0.12 ±0.02	0.11	0.14
Silicon [%]	(0.5... 0.8) ±0.005	0.56	0.50
Manganese [%]	(1.3...1.7) ±0.1	1.46	1.57
Chromium [%]	Not greater than 0.3 ±0.005	0.05	0.15
Copper [%]	Not greater than 0.3 ±0.005	0.13	0.28
Nickel [%]	Not greater than 0.3 ±0.005	0.24	0.24

In order to determine the conformity of the investigated fragments mechanical properties to the requirements of the standard documentation, tension and impact strength tests were carried out. Mechanical properties – ultimate strength, yield strength and elongation – were determined on flat XV-type samples in accordance with GOST 6996-84. Impact strength was determined on standard VI-type (Figure 1a) samples 10×10×55 mm in size with U-shaped (Mesnager piece) at temperatures +20C °and -40C°. Tests were conducted according to GOST 1497-84 and GOST 7564-84.



a b

Figure 1. Impact strength type samples
(a – U-shaped (Mesnager piece); b – V-shaped (Charpy specimens))

Figure 2 provides stress-strain diagrams of cross-section specimens cut out from the first and second tank rings: the former has a clearly pronounced yield plateau, the latter has almost none. The results of processing the machine stress-strain diagrams are given in table 2.

Impact strength testing of Charpy specimens is harsher, as their notch radius is 0.25 mm. These tests allow us to reveal more precisely the susceptibility of steels to brittle fracture [5-9]. IX-type specimens (Charpy specimens) were tested at temperatures +20°C, -5°C and -40°C. Temperatures +20°C and -5°C were taken in order to determine the conformity of the investigated steels to SNiP 2.05.06-85 requirements. Temperature -40°C was taken considering the region of tank construction. Tests were conducted on an impact pendulum-type testing machine. Negative temperatures were gained by means of liquid nitrogen. Aviation kerosene was used as a coolant. Temperature was measured with a low-temperature thermometer graduated in 0.1 ºC. Tests were conducted according to GOST 9454-84.

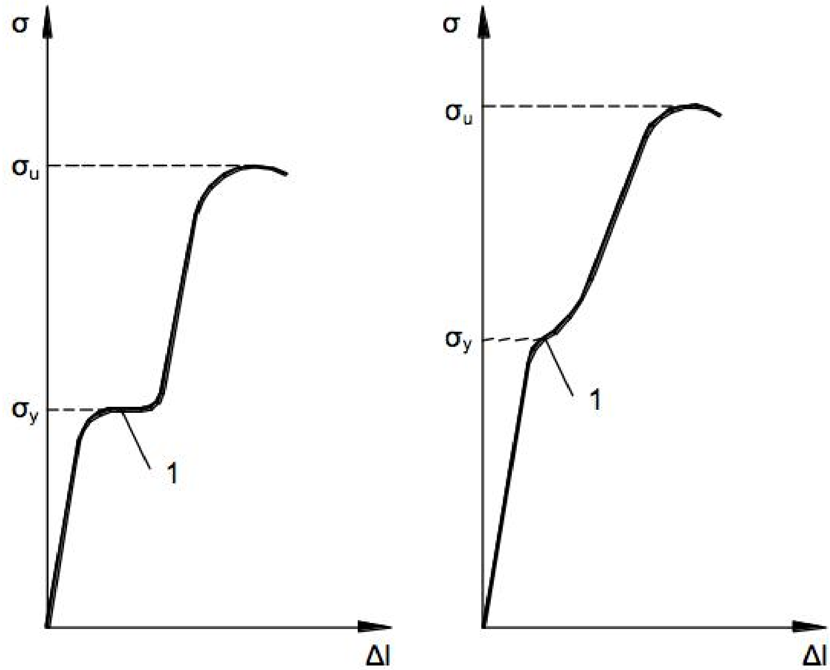


Figure 2. Stress-strain diagrams of specimens from the first and second tank rings
(1 – yield plateau)

Table 2. Mechanical properties of investigated steels.

Physical property	Standard value for steel 09G2S (GOST 19281-89*)	Value for fragment of first tank ring	Value for fragment of second tank ring
Ultimate strength σ_u [MPa]	470	480	540
Yield strength σ_y [MPa]	325	330	353
Elongation ε [%]	21	24	18
Impact strength KCU [J/cm^2]	> 59	100 – 105	57 – 60
Impact strength KCU^{-40} [J/cm^2]	> 39	65 – 74	32 – 35

As is clear from tables 2 and 3, the values of impact strength for the first ring exceed the values specified by regulatory documents. The results of testing a fragment from the second ring are different. At room temperature the impact strength matches the requirements. However, at temperature -40°C the impact strength is below standard values. Besides, when testing Mesnager pieces the difference is small, and on Charpy specimens the values differ very strongly – almost twofold.

Table 3. Impact strength when testing Charpy specimens.

Impact strength	Standard value for steel 09G2S (SNiP 2.05.06-85)	Value for fragment of first tank ring	Value for fragment of second tank ring
KCV [J/cm^2]	Not regulated	83 – 86	46 – 51
KCV^{-5} [J/cm^2]	Not regulated	Not determined	27 – 31
KCV^{-40} [J/cm^2]	> 29.4	35 – 41	14 – 18

Thus, it demonstrates that the rings made of the same grade steel have different properties. To find out what is the difference in steel properties caused by, hardness measurement has been performed. The results of hardness measurements are given in table 4. Hardness measurements were conducted with a TSh-2M device at ball diameter D=10 mm and load P=30 kN. Tests were carried out according to GOST 9012-59.

Table 4. Results of measuring hardness of investigated steels.

Fragment	Value of parent metal hardness [HB]	Value of assembly weld hardness [HB]	Value of hardness in heat-affected zone of assembly weld [HB]
The first ring	148	155	-
The second ring	166	176	170

As it can be seen from the data given in table 4, the value of hardness for the second ring is greater than that for the first one. The value of hardness depends on where it was measured.

3. Discussion

Design structural stresses in vertical steel tanks reach up to 80 % of the yield point. Under such conditions, local defects that are stress concentrators cause the formation of zones where the value of yield strain is so great that micro cracks occur at an early stage of loading.

There are cases when structures, for example, gasholders, that passed acceptance tests at loads 1.4 times exceeding the design ones, either were destroyed after 5 years of operation or previously unregistered cracks were discovered upon inspection.

Analysis of test results allows us to deduce an inference that referring to changes in mechanical properties of a material of vertical steel tank design elements as operational defects is justified (table 5).

Table 5. Changes in mechanical properties of investigated steels.

Physical property	Change for fragment of first tank ring	Change for fragment of second tank ring
Ultimate strength σ_u	2.1 %	14.9 %
Yield strength σ_y	1.5 %	8.6 %
Elongation ε	14.3 %	-14.3 %

It is obvious that the presence of assembly welding fixtures speeds up degradation processes in steel. So, in the zone of the assembly weld changes in mechanical properties are considerably greater: ultimate strength is increased by 15 %, yield strength – by 9 %. A hardness increase in this zone is thus observed.

Almost all large-size tanks, operating in the oil transportation system, were assembled by the scrolling production technique. Some disadvantages of this technique are multiple imperfections of the geometric shape and assembly welded joints of metal structures. At present, as the operation life of most tanks exceeds the designed one, there arose a problem of evaluating the stress-strain state of such VSTs.

The place of crack formation in the investigated tank coincides with the largest wall deformations under the operational load. This can indicate a more intensive development of fatigue damage in metal tank structures with imperfections of their geometric shape.

Timely and high-quality evaluation of the technical state and elimination of defects of structures improves their service reliability. Such evaluation can be obtained only based on a complex inspection, including non-destructive testing of weld joints, metal quality testing, well thickness control, geometric shape control, etc. The required extent of such inspection considering the operation life: for new tanks — total control, for in-service tanks — partial control, for tanks at the end of operation life — inspection according to an individually developed program and investigation of changes in metal properties of tank structures.

4. Results and conclusion

The results of studying the RVS-20000 tank metal after long-term service show a change of mechanical properties, with the greatest changes occurring in a place of the assembly welded joint at the second ring level. At operation life of more than 10 years there occurred an increase in ultimate strength by 2 % and yield strength by 1.5 % for a defect-free design element – the first belt of the tank wall; and approximately by 15 % and 9 %, correspondingly, for the second ring having an assembly welded joint. This confirms the necessity to record changes in mechanical properties of metal as an operational defect of vertical steel tanks when determining the residual operation life during technical diagnosing. It is necessary to pay special attention to places of welding the assembly welded fixtures.

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