Materials safety: article exercise

You are working as a materials expert in your organization and your responsibility is to guarantee safe and efficient use of materials in your facility. One day, a failure in similar facility is brought to your attention, and you need to investigate the possible implications this failure has for your facility. Your job is to interpret and analyze the given failure report and to write a report, which will allow others in your organization to understand the key developments and causes leading to the failure and the necessary actions for prevention of such failures.

Read the given article and analyze the failure. Describe, how the deformation and failure mechanisms presented during the course are reflected in the case and establish the chain of actions leading to the failure. The report should work as an introductory material to your team; it should not be very long but it should enable other team members to understand the key features of the failure without reading the failure report itself.

In addition to establishing the primary cause of the failure, show why alternate failure mechanisms can be ruled out. Some failure mechanisms have not been discussed in the course yet. Conduct the analysis using your present knowledge on the subject.

If the author of the failure analysis has, in your view, neglected to address some aspects of the failure, you may indicate this in your report and suggest tests or actions that should have been done to clarify the issue.

Prepare your response by editing this word document and export it as PDF. The file name identifies you and the article. Do not change the file name (other than the extension to pdf). E-mail the pdf to "materials.safety@iikka.fi".

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Materials Safety analysis report on corrosion of brewery tankers

Problem Overview of the report:

The report discusses a problem faced by the brewery industry concerning corrosion in buffer tanks. Stainless steel is a popular choice in breweries for the water tanks for its corrosion resistance, but it has been observed to experience corrosion issues after 12 years in operation. The report outlines a specific case where the tank used to store warm water in a brewery exhibited signs of corrosion. Through different analyses, the report seeks to diagnose the types of corrosion and their underlying causes, emphasizing the role of possible factors in corrosion such as water treatment, pH adjustment, and the presence of chloride ions.

A. Description of investigation methods applied

- What means of investigation were used in the failure analysis?

The author tries to determine whether the threat of corrosion is associated with the presence of the water environment surrounding the tanks. From the report, the means of investigation for the failure analysis included:

1. Observations on the cracks: After removing the corrosion deposits with a paper, the tank reveals the cracks, pits, and etchings, possibly caused by the chloride water.
2. Chemical Composition Analysis: The author provides the chemical composition of the 1.4301 austenitic stainless steel, which can account for its specific corrosion impact.
3. Stress calculations: due to the presence of visible cracks on the tank surface, the stresses resulting from hydrostatic pressure were calculated, which were reported to be within permissible limits of hot and cold water.
4. Electrochemical Investigations: these were carried out on the 1.4301 steel, which was the material from which the examined tank was constructed. This is the main methodology in the report to study the chemical properties of the contained water.

- What computational methods were used?

The author lists a couple of computation methods as follows:

1. Cyclic polarization tests on three-electrode system with the use of Gamry Instruments electrochemical measurement to determine the susceptibility of the alloy to pitting corrosion.
2. Langelier corrosivity indexes were calculated in different temperatures to determine the water corrosivity at various stages
3. Scanning electron microscope (SEM) research was conducted on the steel surface. This studied material was extracted from where the corrosions occurred on the tank.

- What material or results were obtained?

The author studied 3 different stainless steels: 1.4301 (current in use), 1.4462 (candidate) and 1.4436 (candidate). After the analyses, the author obtained the results based on 4 criteria

1. Susceptibility of 3 candidate stainless steels to pitting corrosion by water at 75 °C prior to pH adjustment: the author concludes pre-treatment water is not aggressive. The probability of pitting corrosion is extremely low for all 3 steels.
2. Susceptibility of 3 stainless steels to pitting corrosion by PH-treated water at 75 °C: only 1.4462 steel is resistant against pitting corrosion, while the others are susceptible.
3. Chemical composition of water: After treatment, the water's pH value decreases from 7 to 5–5.5 level, which increases the chloride ions concentration, making the water more corrosive. The studied steels become more susceptible to pitting and corrosive cracking.
4. Electrical voltage of the stack's inner part: areas with lower potential voltage are more likely to be impacted by pitting corrosion, such as the upper parts of the tanks. It is noted that 1.4301 steel potential is constant with regards to varying temperatures.

The author believed that the tanks should be built with two new austenitic steels instead of the current austenitic steel. Even though these new materials are more costly, it is worthwhile in the long run as they are highly durable against corrosions.

B. The primary cause of the failure and description of the failure mechanism

- What is the primary cause of the failure (also provide reasoning)?

The primary cause of the failure in the study is most likely to be associated with various types of corrosive attacks on the tank. These corrosive attacks, including cracks, pits, and etchings, are attributed to deposit corrosion. The deposit corrosion was driven by the water due to corrosion in the water supply installation. Furthermore, the locations of tank repairs corresponded precisely to the zones of intense stress caused by the pipeline, suggesting a coupled mechanical and corrosive impact as contributing factors to the failure.

The paper did state a line as follows:
"The locations of tank repairs correspond precisely to the zones of intense stress caused by the pipeline. This allows for associating the corrosion with the mechanical and corrosive impact."

This indicates that the primary cause of the tank's failure was a combination of mechanical stress (such as circumferential, longitudinal, and buckling stress) upon the pipeline wall and corrosion by the water supply installation.

- What's the chain of action that led to the failure?

The chronological order of the tank failure is as follows:

1. Deposit Formation: The inner stainless-steel surface of the tank was covered with a dark brown deposit, primarily composed of corrosion products. This deposit was driven into the tank by the water due to corrosion in the water supply installation.
2. Mechanical Impact: An area of the tank, approximately 1.5 m wide, was in the zone of mechanical impact from an external pipeline. Additionally, hydrostatic pressure also causes great pressure on the bottom of the tanks.
3. Coupled effect: The locations of tank repairs matched the zones of intense stress, suggesting that the corrosion was exacerbated by both mechanical and corrosive impacts.

4. Visible corrosive marks: After removing the corrosion deposits, clear cracks and pits were observed, such as a large crack of 50 mm and a small one of 4 mm. Water can leak out from the tank through these cracks. This is the final stage of the tank's failure.

C. Ruling out alternate failure mechanisms

- Can plastic deformation be ruled out? If yes, explain how.

Plastic deformation occurs when the material deforms pass its yielding strength. This can be ruled out as the stresses resulting from hydrostatic pressure were calculated and were found to be within permissible limits for both cold and hot water, suggesting that the stresses were not sufficient to cause plastic deformation.

- Can creep be ruled out? If yes, explain how.

Creep is the slow deformation while the material is subject to persistent mechanical stresses. It can result in failure even if the applied stress is below the yield strength of the material due to long term load exposure. This failure mechanism in my opinion should be seriously considered. The brewery tank is continuously subjected to internal pressures due to the stored warm water. Over time, even if the stresses induced by this pressure are below the yield strength of the stainless steel, the stainless steel can start to be affected by creep. Additionally, creep is more serious at higher temperatures if the warm water in the tank is maintained isothermally. Also, the paper provides that the tank has been in use for 12 years, which fits the time frame of creep.

- Can brittle fracture be ruled out? If yes, explain how.

Brittle fracture can be ruled out since stainless steel is typically ductile at room temperature to warm temperature. Brittle fractures are more likely to occur under high strain rates, such as large impact loadings. In the case of the brewery tank, the operational conditions involve relatively slow and steady internal pressures, leading to low strain rates. If anything, this load could have caused ductile deformation before the brittle fracture.

- Can fatigue be ruled out? If yes, explain how.

Fatigue can be ruled out because there is no description of cyclic loading against the tank wall. The mechanical stress on the wall is mostly constant such as hydrostatic pressure.

- Can environmentally assisted failure be ruled out? If yes, explain how.

Environmentally assisted failure, specifically in the form of corrosion, was the primary concern in the report. The corrosive attacks were driven by the water due to corrosion in the water supply installation. Therefore, this failure should be the top primary concern of the failure. Besides corrosion, environmentally assisted failure also includes hydrogen embrittlement. However, this is not the case here as the report finds that the chloride ions chiefly make the water corrosive.

The paper explicitly states as follows:
"No changes in the steel below the deposit were found, so it can be concluded that the deposit was driven in by the water due to the corrosion in the water supply installation"

D. Recommendations to prevent similar failures in the future

- How should the design, material, use, etc. be developed to avoid similar failures in the future? Provide several alternatives and indicate the most promising.

To avoid similar failures in the future, several design, material, and usage recommendations can be inferred from the paper

1. Material Selection: The paper suggests considering alternative stainless-steel materials. Specifically, the study included 1.4436 steel as a potential alternative material for future tanks. Additionally, 1.4462 steel was recommended due to its good mechanical properties and superior corrosion resistance.

2. Water Treatment: Ensure that the water used in the brewery undergoes appropriate PH treatment to minimize its corrosive aggressiveness. The study emphasizes the chemical composition of water and its temperature to prove its corrosive property.

3. Stress Analysis: Conduct thorough stress analyses, especially in areas where mechanical impacts are expected, such as near pipelines or the bottom of the tank. This can help in identifying potential weak points and reinforcing them as needed.

4. Water tank design: The water tank is high over 18 meters and has a large diameter with over 200 cubic meter volume of water, while the wall is very thin. This is quite dangerous as the load is very large against the not so reinforced tank wall. A good idea is to increase the wall thickness or reduce the height of the tank.

5. Environmental Considerations: Given that the environmentally assisted fracture played a significant role in the observed corrosion, it's crucial to monitor environmental factors, such as chloride ion content in the water, which can intensify corrosion processes.

The most promising methods are the first and second methods, since they are straightforward, easy to implement and relatively low-priced solutions.

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