



Technical Note

Determination of causes of accelerated local corrosion of austenitic steels in water supply systems



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HIGHLIGHTS

- This research presents a case study of accelerated local corrosion of water supply system pipeline.
- Presence of weld decay on AISI 304 steel was shown and its consequences were revealed.
- Formation of galvanic cells related to chromium depletion as a result of sensitisation was studied.

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ABSTRACT

This paper concerns an inspection of a water supply system, made of AISI 304 steel, which showed signs of local corrosion at the weld. Such corrosion caused material perforation after very short periods of operation. It was revealed that steel was sensitised during the welding process. It was also proven that chromium micro-segregation occurred in the alloy leading to galvanic cell formation which initialised the process of pitting corrosion. This paper is a study of corrosion attack types due to negligence during and after the process of welding of the system.

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1. Introduction

Austenitic steel such as AISI 304 and AISI 316 are most often used as elements of industrial structures operated in conditions characterised by higher corrosion aggressiveness. Such steels are expected to be very resistant, in particular in water with a low content of chloride ions. For many water supply systems, however, accelerated degradation due to corrosive factors can be observed. Such resistance is ensured by a thin passive layer on the steel surface. Degradation of the passive layer, which is usually caused by external factors, can result in enhanced susceptibility of steel to local corrosion.

A key factor that causes the occurrence of local corrosion is the presence of chloride ions. There are many theories pertaining to their influence on pitting corrosion [1–3]. Most of them suggest adsorption of Cl^- ions on the layer surface which later becomes oxide-depleted. Safe concentrations of chloride ions that do not cause pitting corrosion of austenitic steels are conditioned by the grade of steel as well as many environmental factors. The Langelier

Saturation Index (LSI) is a popular method of evaluating water quality data to determine if the water has a tendency to form chemical scale. In order to use this index, the following laboratory analyses are needed: pH, conductivity, total dissolved solids, alkalinity, and total hardness.

Local corrosion can be often observed along sections of pipelines with a very limited flow and in standing water, e.g. in fire protection or potable water systems. In such cases, crevice corrosion is particularly hazardous. This type of corrosion is also hazardous for connections of elements [4] or in areas where organic coating is loosening [5]. Further, anaerobic areas also contribute to corrosion due to microbiological activity where e.g. sulphate-reducing bacteria (SRB) and/or iron-oxidising bacteria (IOB) can grow [6,7]. It is believed that even up to 10% of all corrosion damage can be caused by such microbiological activity.

Buried elements of steel structures, arranged in urbanised areas, are even more exposed to sources of chloride ions from salt used by road services to sprinkle roads. Conducted research has proven that even up to 50% of salt penetrates locally to surface waters [8], and the content of chloride ions can reach even up to 2700 mg/l [9].

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Due to high temperatures associated with the welding process, where such temperatures can cause structural changes in steel, the heat-affected zone at the weld is often the area where accelerated local corrosion occurs. After welding, it is important that the surface that could be in contact with water has a homogeneous composition. Any crevices formed during the process should also be removed. Due to steel sensitisation during the welding process, areas of higher susceptibility to intergranular corrosion are often created. Such corrosion is often associated with pitting corrosion resulting from concentration cells in the alloy created due to uneven distribution of chromium. Once a pit has been created, it acts as an anode depolarised by an extensive cathodic area around the pit, and causes intensive degradation. Most often pitting occurs in heterogeneous materials. This complex corrosion process in the heat-affected zone, causing material loss along the weld, is referred to as weld decay [10–12]. Degradation due to local corrosion can be much faster than could be expected for the construction materials used and corrosive aggressiveness of the environment.

In addition, a combination of corrosive and mechanical factors such as erosion or cavitation erosion–corrosion can have a synergy effect that usually enhances the rate of material degradation. This type of hazard occurs particularly in systems with a turbulent flow of liquid [13–16].

This paper is a case study relating to the causes of local corrosion in the water supply system.

2. Experimental

The structure being the subject of this investigation is an element of a water supply system, described in the next chapter. Corrosion causes pipeline perforation resulting in the appearance of corrosion products on the outer walls. This effect can be observed in the vicinity of welded joints. For experimental purposes, a section of the pipeline, including the weld and the parent material at a distance of around 5 cm from the welded joint, was sampled. The inner diameter of the pipe under examination was equal to 30 cm and its thickness was 0.4 cm. Weld bead width was around 1.2 cm while effect of welding in the form of discoloration was visible up to 1.5 cm from the weld bead. Also for the purpose of the experiment, the film of corrosion products on the inner side, was etched in a mixture of organic acids and corrosion inhibitors used for cleaning chromium–nickel steel.

Within the testing procedure, the grade of the steel subjected to testing was identified by optical emission spectrometry with glow discharge and with the use of spectroscope LECO GDS850A. In addition, physical and chemical parameters of water flowing through the pipeline were analysed to determine the LSI index. Analytical tests of water were carried out by means of the colorimetric method with the use of a Palintest Photometer 5000 system offering an instrumental method of a wide range of water tests. Determination of dry residue was carried out in accordance with standard PN-EN 12880:2004. Other parameters determined included: pH – with a microcomputer meter CP-551, conductivity – with a microcomputer conductometer CC-315, oxygen – with an oxygen meter CO-411.

An analysis by means of the cyclic polarisation method carried out within this study was conducted with the use of a three-electrode system where the tested pipeline section was the working electrode. Its surface area was 2 cm². A saturated calomel electrode (SCE) was used as a reference electrode, whereas platinum gauze served as the counter electrode. A 150 ml solution of water transported in the pipeline and polarisation rate of 1 mV/s were applied. For the purpose of tests, a potentiostat manufactured by GAMRY International was used.

Topography analysis of sample was carried out on Hitachi S-3400N scanning electron microscope with a tungsten source and variable chamber pressure (VP-SEM). Pictures were taken in the secondary electrons mode (SE), under 20 kV accelerating voltage and 10 mm working distance, proven as the optimal conditions. The microscope was equipped with an energy-dispersive spectroscope EDX, manufactured by ThermoScientific, as an attachment.

3. Results and discussion

3.1. Inspection of the water supply system

Various areas of the system were inspected, corrosion had the same character and origin for every element of the pipeline. Most often corrosion occurred just at the weld or in its vicinity, not further than 3 cm away from the weld. Washed-away corrosion products flow slowly out of the perforation areas. The photos in

Fig. 1 illustrate corrosion damage of different pipelines within the water supply system, in particular: pumping station (Fig. 1A and B), rinsing water system (Fig. 1C), water filtration system (Fig. 1D). In addition, it was found that there were attempts to remove perforation due to corrosion by pad welding (Fig. 1D).

A preliminary visual inspection of the pipeline showed that compacted corrosion products were accumulated on its inner side (Fig. 2A and B). The areas correspond to the spots where stains on the outer side were located. Moreover, in the vicinity of the weld, the entire area was covered with a thin layer of rust. Its presence indicates that there was no protective passive layer on the steel surface and iron corrosion occurred as a result. Once the section was cleaned, dark line located about 1 cm from the weld was found (pointed out with arrows in Fig. 2C). In this area, macroscopic pits were revealed under the agglomeration of corrosion products (Fig. 2D).

An internal inspection of the pipeline carried out upon collecting the specimen showed that there were no such corrosion products further away from the weld. The photo in Fig. 3 reveals the same dark line within a direct distance from the weld. Its presence indicates an area of a thick layer of chromium oxides; the layer was formed as a result overheating during the welding process [17].

3.2. Water analysis

The pipeline is used for transporting untreated water. Its detailed composition as well as characteristic physical and chemical parameters are summarised in Table 1.

Based on the list of the above parameters the Langelier Saturation Index (LSI) was determined. The tested water is characterised by considerable hardness, a high total content of chlorides and sulphates, average conductivity, and a low oxygen content. There is no tendency for deposits for cold or hot water (at a temperature of 55 °C). Conditions for the formation of the passive layer are met, whereas there is no tendency to form deposits limiting the risk of crevice corrosion. There is a higher risk due to contact corrosion. In particular, a high content of chlorides significantly increases susceptibility to pitting corrosion in the aforementioned environment.

3.3. Local corrosion of steel

In most cases, the weld constitutes an area which is considerably different from the parent material in terms of its micro-structure, and even its chemical composition. These differences can contribute to the formation of galvanic cells with various stationary potentials, and as a result, to corrosion of the area in the vicinity of the weld. In the very weld there are also micro-cells formed as a result of micro-structure segregation which occurs during solidification. If material used for welding is different from the parent material, such a situation can result in a considerable difference in potentials, and consequently, individual areas at the weld become more active and prone to corrosion. For instance, if welding AISI type 304 steel with metal which is rich in chromium and nickel, high differences in concentration of these elements influence weld corrosivity.

An analysis of chromium, nickel, molybdenum and carbon which was performed in bulk of the material to identify the steel grade showed that this is austenitic steel, grade AISI 304. Both the chromium and nickel content fall within lower allowable limits set out in the standard (Table 2). A spectrophotometry analysis was carried out for the parent material at a distance of about 5 cm from the weld and at the weld joint. A comparison of composition at both points was aimed at determining the validity of selecting the weld metal for the purpose of pipeline welding.

Although the materials applied for welding purposes were selected properly, the choice was not optimal. Steel AISI type 304

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