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Original article

Pitting Corrosion of Austenitic Stainless Steel Weld in Brewing Industry: Case Study

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ABSTRACT

In this paper, a case study of pitting corrosion of austenitic stainless steel weld of a pipe in brewing industry is presented. Pitting corrosion caused leakage and the cause of corrosion was sought to be found. After a comprehensive investigation, comprising of visual inspection, chemical composition, hardness, tensile and metallographic testing. It was found that there are two reasons that influenced the occurrence of pitting corrosion, both related to welding process. The first is the unnecessary cleaning of the inside of the pipe by wire brush tool on the power drill, introducing creases that held the acidic cleaning agent. The concentration of the acid rose after evaporation that caused the corrosion, aided by the tinting of the weld zone. Tinting was caused by insufficient oxygen purging from the inside of the pipe by shielding gas. After welding, no passivation was performed, which left the heat tinting layer with compromised corrosion resistance.

Key words: *Brewery, Pipe, Corrosion, Welding*

1. INTRODUCTION

Brewing is one of the oldest and most important area within food and beverage industry in the Autonomous Province of Voivodina, Republic of Serbia [1]. The mainstay of equipment design and fabrication, from the sanitary perspective is stainless steel, or more specifically, austenitic stainless steel. These materials comply with the 3A sanitary standards established in accordance to [2].

There is a wide range of austenitic, or non-magnetic stainless steels, alloyed with up to 26 wt. % of chromium (Cr), up to 35 % of nickel (Ni), and other alloying elements, such as Manganese (Mn), Magnesium (Mg) and Titanium (Ti) [3]. However, vastly the most frequently used stainless steel alloy in food industry is the lower grade AISI 300 series of steels. Within this series, approximately 50 % of all stainless steels produced is the 304 steel (EN X5CrNi18-10), having typically 17.5-19.5 Cr and 8-10.5 % Ni. This type of steel has several variants, some examples being 304L and 304H (X2CrNi19-11 and X6CrNi18-10 respectively), having variations in carbon (C) content. Namely, 304 contains up to 0.08, 304 L up to 0.03 and 304H up to 0,1 % C [4]. These variations in carbon are related to increased weldability (304L) and increased heat resistance (304H). The increased weldability is due to the decreased carbon content, which is closely related to the reduction in susceptibility to intergranular corrosion, that is, the formation of $Cr_{23}C_6$ at grain boundary and depletion in Cr content near grain boundary leading to a decreased corrosion resistance [5]. The increased weldability is deemed of greater importance compared to a reduced strength of 304L compared to 304 austenitic stainless steel

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[6]. In this paper, more specifically presented as a case study, the cause of failure in form of pitting corrosion that occurred near the weld of a brewery pipe is presented.

2. EXPERIMENTAL

2.1 *Statement of a problem*

Pipelines in a local brewery were replaced due to regular maintenance process done periodically. The replacement was done by an external contractor and no data on welding procedure and parameters were available, except of the welding process used, manual Gas Tungsten Arc Welding (GTAW) and common shielding gases: Argon and forming gas for root protection (5-12 % H_2 in N_2) [7]. Three months after the replacement, leakage in the area near the weld occurred in multiple locations. This was noticed by the brewery maintenance teams and the Faculty of Technical Sciences was contacted in order to determine the cause of failure.

2.2 *Characterization*

The pipes affected by the corrosion had the diameter of 100 mm, with the wall thickness of 2 mm. The following tests were performed: visual inspection, metallographic, chemical composition and hardness testing.
Chemical composition of specimens was determined by optical emission spectrometry (OES), using ARL2460 device. Vickers hardness was tested by using VEB HPO-250, with the loading of 10 kgf, in the weld metal, heat affected zone near melt line and in the base metal. Tensile testing was done by mechanical tensile testing machine VEB ZDM 5/91, on two specimens that were taken in transverse direction to the weld, that is, in longitudinal direction to the pipe. Tensile specimens were cut so that corrosion pits are avoided, to assess the weld integrity in relation to base metal nominal strengths. Metallographic preparation was performed on Struers set of devices for cutting, mounting, grinding and polishing. Grinding was done with abrasive papers, from P150 to P2500, while polishing was done with diamond suspensions with 6, 3, 1 and ¼ µm particle size. Etching was done with Aqua regia. Specimen examination was performed by using Leitz Othoplan light microscope.

3. RESULTS

3.1 *Chemical composition*

Chemical composition of the tube is shown in Table 1. It can be seen that the pipe material fully corresponds to the AISI 304L austenitic stainless steel.

Table 1. *Chemical composition of the tube and 304L steel nominal values as a reference in mass %*

	C	Si	Mn	S	Cr	P	Ni	Fe
Pipe	0.03	0.32	1.67	<0.001	18.09	0.029	8.02	bal.
304L*	≤0.03	<0.75	<2	<0.03	18-20	<0.045	8-10.5	bal.

* Standard EN10217-7 [4].

3.2 *Visual examination*

The examined specimens are shown in Fig.1. In Fig.1a, the weld zone is shown, with grinding marks that were the result of preparation done before welding. White arrow indicates corrosion spots within the ground area, at the distance of up to around 10 mm from the weld In Fig.1b, c, a close up depiction is presented, where Fig.1b shows the external surface with fewer larger perforations compared to the internal surface shown in Fig.1c. Grinding marks can be also observed in Fig.1c. Furthermore, tinting area around the weld can be seen, closely corresponding to C-level of heat tint, that is, 32 ppm oxygen concentration, Fig.2. [8]. Heat tint is the surface that contains different inhomogeneities and damage to the oxide layer that may impair the passivity of stainless steel. This surface is electrochemically active and liable to corrosion. Although recommended oxygen concentration is under 1 ppm (level A in Fig.2) [9].

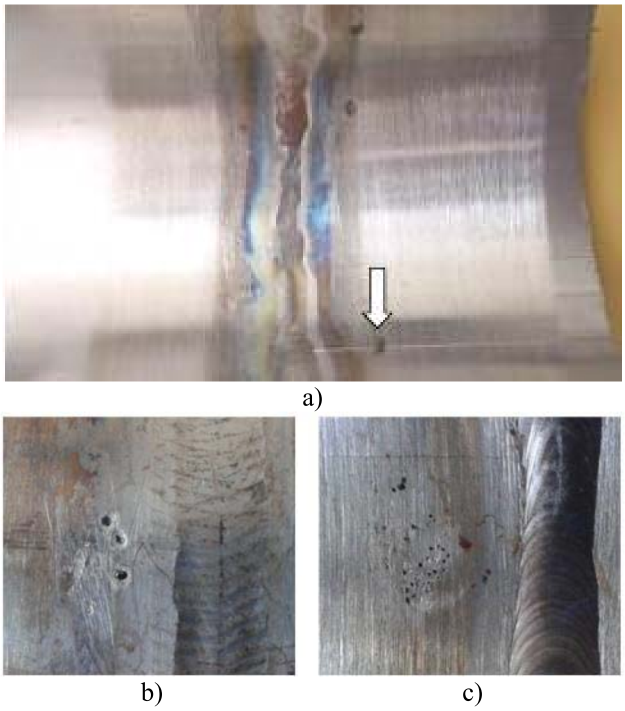

Fig.1 *Specimens examined, the area shown is near 6 h in the tube (bottom part)*

Fig.2 *Heat tint levels [8].*

3.3 *Metallographic examination*

Cross section of the pipe in the corrosion zone is depicted in Fig.3, where the top is the inside of the pipe. Two pits are found, one partially, and one fully penetrating the wall, clearly indicating that the corrosion first occurred in the inside of the pipe. As the pipe is used to transport beer, the most probable cause of corrosion is the cleaning in place by an alkaline cycle (0.5-2 % NaOH at 60-80ºC), whereas the acidic cycle is performed with 1 – 2 % HNO_3 at ambient temperature. In Fig. 4, weld zone is presented, with large non-penetrating corrosion pits and the weld metal with typical morphology. Microstructures of base metal and melt line including weld metal are shown in Figs. 5 and 6. Base metal microstructure is austenitic (Fig.5), which is in accordance with the chemical composition shown in Table 1. Weld metal has a columnar morphology in the direction of heat transfer towards base metal. Finally, in the heat affected zone, there is austenitic grain coarsening.

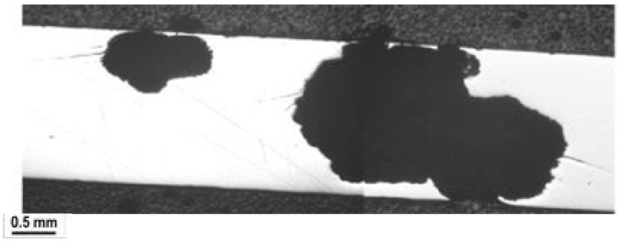

Fig.3 *Cross section of the pipe in the corrosion zone*

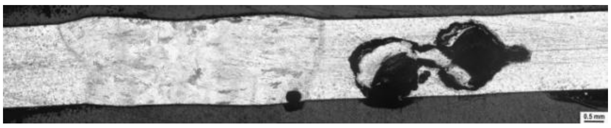

Fig.4 *Weld zone showing weld metal base metal and corrosion pits*

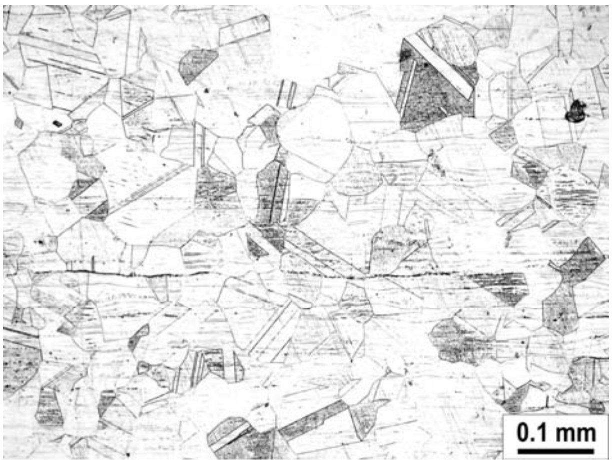

Fig 5 *Base metal microstructure*

3.4 Hardness test

Vickers hardness test results in base metal, heat affected zone (HAZ) near melt line and weld metal is shown in table 2. The lowest hardness was obtained in the weld metal, followed by HAZ near melt line. Hardness values in the HAZ near melt line are lower compared to base metal due to austenitic grain coarsening effect reported in Fig. 6.

Table 2. Vickers hardness of the weld (HV10)

Base metal			HAZ-near melt line	Weld metal			HAZ-near melt line	Base metal		
251	216	199	165	159	150	161	164	170	169	187

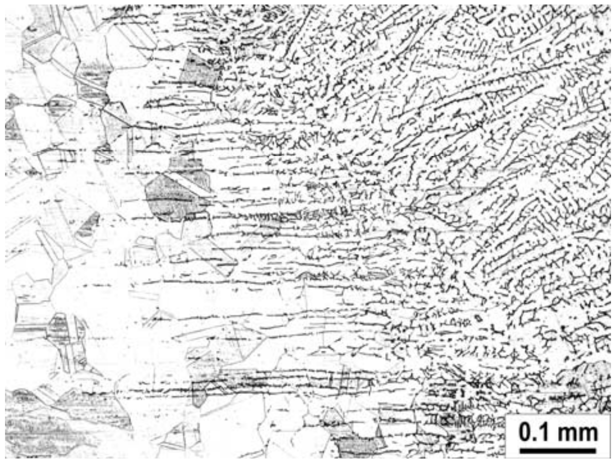

Fig.6 Right-weld metal, center-melt line, left heat affected zone

3.5 *Tensile testing*

Tensile testing results are shown in Table 3. It can be seen that strength values are in agreement with 304L austenitic stainless steel nominal values, which is acceptable and in accordance with hardness values in Table 2. This proves that the selection of consumable material was correct.

Table 3. Tensile testing results and nominal strength values for 304L steel

	Yield strength $R_{p0,2}$ [MPa]	Tensile strength R_m [MPa]	Fracture location
1	385	597	Weld metal
2	385	567	Weld metal
304L*	≥170	485	-

* Standard EN10217-7 [4].

4. DISCUSSION

The obtained chemical composition, as well as microstructures of base metal and weld metal suggest that the base material is 304L, which is well suited for welding. Furthermore, based on tensile testing results, specimens cut perpendicularly to the weld in areas where no corrosion was observed, consumable material was selected correctly. There are two causes of pitting corrosion, related to pre-welding activities that were done and post-welding activities that we not done.

Pre welding grinding, probably by wire brush tool mounted on the power drill, that was done before welding, was done supposedly to clean the inner part of the pipe was unnecessary. It created creases in material, which kept acidic cleaning agent. Although containing a relatively low 1 – 2 % HNO_3 in water, which is not sufficient to cause corrosion in 304L austenitic stainless steel, hence it is used for cleaning purpose. However, creases created by wire brush kept the acidic agent, water solvent evaporates and the concentration of HNO_3 is increased to the level that makes it corrosive [10]. Stainless steel surface should have been kept smooth, in as-received condition [11]

On the other hand, although the forming shielding gas was used, heat tinting could be observed. It is an indicator of the presence of over 1 ppm oxygen in the pipe and closer to 32 ppm during welding. That means, forming gas was not applied long enough to expel oxygen from the inside of the pipe. Heat tinting further degraded corrosion resistance of the pipe material. To avoid corrosion problems, heat tinted welds should have been post-treated with HF, HNO_3 or H_2SO_4 (passivation process*)* [12].

5. CONCLUSIONS

According to the presented results, the following conclusions can be drawn:

- Pitting corrosion occurred due to welding.
- Welding consumable was selected correctly, enabling sufficient strength values.
- Preparation of the inside of the pipe in form of wire brushing caused creases to occur. These creases keep a certain amount of acidic cleaning agent, with relatively low concentration. After the evaporation of solvent, the concentration rises, becoming corrosive for the pipe material.
- During welding, the inside of the pipe was protected by shielding gas, however, an insufficient purging time caused the occurrence of heat tinting. This layer has a compromised corrosion resistance.
- After welding, passivation of heat tinting could have been performed, however, visual inspection proved that such treatment has not been done.

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