The Premature Deterioration of Zinc-coated Steel Pipes in Water Distribution System

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Abstract

This paper presents examples of improper materials selection in choosing a pipe for a hot water distribution system. Despite the recommendations of both European Standards and Polish Research & Development Centre COBRTI zinc-coated steel pipes were used for piping in conditions under which the premature corrosion failure was observed.

Keywords

Zinc-Coated Steel Pipe; Internal Corrosion; Water Distribution System

Introduction

Iron and steel pipes have been used in water distribution systems for over five centuries (Sarin et al., 2001). Economically, modern zinc-coated steel pipes are inexpensive and recyclable. With a long life span, such material is very attractive. Zinc coatings protect steel by providing a physical barrier as well as cathodic protection for the underlying steel. In this process, zinc as more ignoble metal is acting as a sacrificial anode while the steel(as cathode) will not be attacked. However, there are many reports of galvanized steel water pipe failures due to corrosion, after several months or few years of service life(Wilmot et al., 2006, Bae et al., 2007). Accelerated corrosion occurs under certain conditions of flow water chemistry. The internal wall of the steel pipe exposed to aqueous environment (flow water) usually suffers more severe corrosion (so-called internal corrosion) than the external wall exposed to indoor conditions (Wang et al., 2012). Many water distribution systems begin to experience pinhole leaks caused by pitting corrosion on the internal surfaces of the piping. Corrosion of zinc in flow water is a complex process controlled largely by water chemistry and temperature. Relatively small differences in water chemistry can produce relatively substantial changes in corrosion products and rate(Amer. Galv. Ass., 2000).A coating of zinc protects galvanized pipe, but when corrosion occurs, depositing high levels of zinc and iron into the tap water.The zinc coating on galvanized pipe may contain lead, copper, cadmium, chromium, aluminum, barium, and other impurities. As a result of these impurities, corrosion of galvanized pipe may result in the release of trace metal concentrations(Amer. Water Works Ass., 2011).

Contemporary regulations in many countrieseven prohibit the use of galvanized steel pipes in drinking water systems and do not recommend for hot water circuit(The Austr. & NZ Stand., 2003). Today, almost all installations in Denmarkare built with pipes of stainless steel and polymer materials. In many other European countries copper pipes arestill widely used, whereas the use of hot dip galvanized steel pipes is decreasing(Hilbert et al., 2010). In some countries, including Poland, galvanized steel piping is still popular and this paper presents the investigations of hot water piping failure due to the use of galvanized steel in two regions (north-east and south-east of Cracow, Poland) supplied by two different public-supplied water sources in the city.

Material and Method

The pipe samples which forms a part of two hot water distribution systems exposed approximately: first one for 2 years (region I) and second one for 5 years (region II) to flow water delivered by two public-supplied sources in the city has been considered for the study. After this short service life galvanized pipes experiencing pitting failures, as it shown in Figure 1 (after 2 years of service) and Figure 2 (after 5 years of service).

FIG. 1. PITTING PERFORATION ALONG THE WELD SEAM, 3/4" PIPE AFTER 2 YEARS OF SERVICE, REGION I

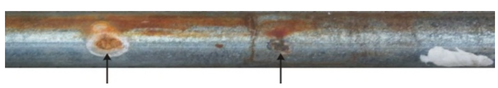


FIG. 2. MAGNIFIED IMAGE OF PITTING PERFORATION ALONG THE WELD SEAM, 5/4" PIPE AFTER 5 YEARS OF SERVICE, REGION II

These longitudinally welded pipes were made of galvanized L235 steel and the elemental chemical composition, determined by use of Foundry-Master WAS spectrometer, do meet requirements stated in EN 10224:2004. Figure 3 shows an example of the microstructure of investigated L235 steel (transverse direction).

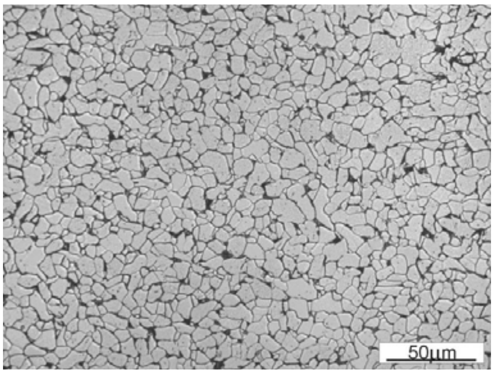


FIG. 3. AN EXAMPLE OF OFINVESTIGATED L235 STEEL, 2% NITAL

Images of the deposits present in the interior of investigated pipes are shown in Figure 4. As shown, on the inner diametral surfaces the pipes were in almost all cases filled with corrosion products formed primarily as tubercles.

a)

b)

FIG. 4. REPRESENTATIVE EXAMPLES OF THE DEPOSITS PRESENT IN THE INTERIOR OF EXAMINED PIPES: A) REGION I PIPE, B) REGION II PIPE

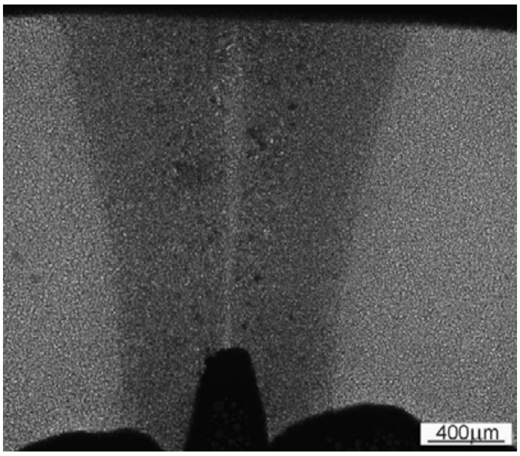
In both cases, chemical analysis of the deposit showed that it consisted mainly of Fe_2O_3 (74.29% for region I, 75.78% for region II).Underneath the tubercles the deep corrosion pits were found, as it is shown in Figure 5. At the corroded internal surfaces the large longitudinal perforations through the wall that followed the weldment seam are observed. As it was stated by (Wilmot et al., 2006), the process of welding creates a high strain energy region relative to the base material microstructure of the pipe and produces a locally accelerated rate of pitting corrosion so localized corrosion attack along the bond line of electric resistance welds (ERW) and flash welds (FW) leads to the development of a wedge shaped groove. Examples of cross section through such wedge shaped groove, close to the perforation area, are presented in Figure 6.

Of course, corrosion outside seam weld area can also lead to pipe wall perforation and water leak, but the corrosion attack is more prominent at the welded seam and first water leaks were observed in that region as it was shown in Figure 1 and Figure 2.

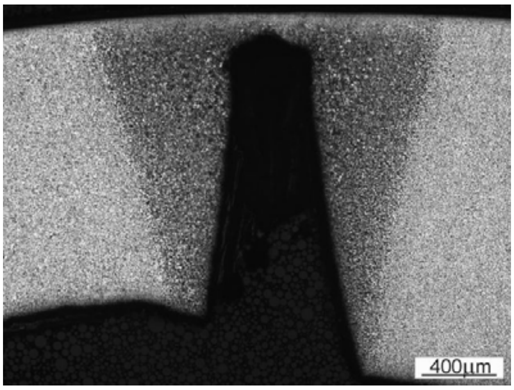
a)

b)

FIG. 5. REPRESENTATIVE EXAMPLES OF THE DEPOSITS PRESENT IN THE INTERIOR OF EXAMINED PIPES: A) REGION I PIPE, B) REGION II PIPE



a)



b)

FIG. 6. CROSS SECTION THROUGH THE WEDGE SHAPED GROOVE, CLOSE TO THE PERFORATION AREA, 2% NITAL

The premature corrosion failure of zinc-coated steel pipes in both examined hot water distribution systems was due to the loss of the internal protective zinc layer as most probably the result of inadequate water chemistry, which will be discussed later. An example of the break in zinc coating on the inner pipe surface which promotes further pit initiation and growth is presented in Figure 7.

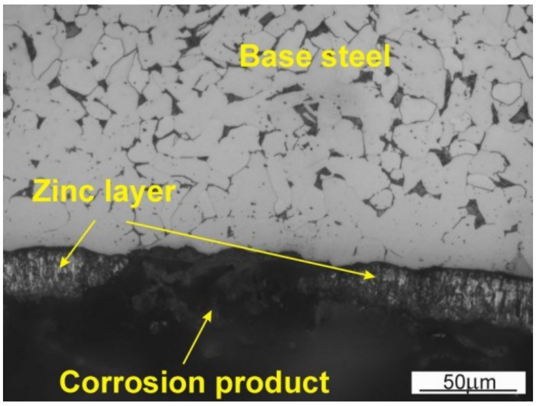


FIG. 7. THE BREAK IN ZINC COATING ON THE INNER PIPE SURFACE

According to the European Standards (Euro Norm 2005, DIN 2013) and recommendations of Polish Installation Technology Research & Development Centre COBRTI Instal, there are conditions under which galvanized steel pipes will sustain corrosion damage. One of the main factor influencing corrosion of zinc-coated pipes is the water composition. The influence of chloride, nitrate and sulphateions on pitting corrosion is determined by the so called concentration ratio S_1 calculated from the equation:

$$S_1 = \frac{c(Cl^-) + c(NO_3^-) + 2c(SO_4^{2-})}{c(HCO_3^-)}$$

where:

$c(Cl^-)$ - chloride ions concentration,

$c(NO_3^-)$ - nitrate ions concentration,

$c(SO_4^{2-})$ – sulphate ions concentration,

HCO_3^- - hydrogen carbonate ions concentration.

According to EN 12502 (Euro Norm, 2005) pitting corrosion of zinc-coated steel pipes is extremely unlikely with S_1 values below 0,5 and very likely with S_1 values above 3.

Elaborated by the Polish Installation Technology Research & Development Centre COBRTI Instal recommendations for materials selection (COBRTI, 2002)provide a list of region in Poland in which water chemistry (including concentration ratio S_1) may cause premature deterioration of piping in water distribution system, depending of used materials (iron, steel, copper, plastics and related). Both studied in present work hot water distribution systems use water supplied from two different sources in two separate distribution networks listed in work (COBRTI, 2002) as sources of high concentration ratio S_1 where use of zinc-coated steel pipes is strongly not recommended. Above mentioned recommendations are based on long-term chemical analyses of distributed water.

Similar long-term study of water chemistry was performed for the two transit lines carrying water to above mentioned region I (Niedziołek et al., 2011). It was stated, that this water is characterized by low buffering capacity, which adversely affect its corrosion properties. Unfavorable in this respect was the Ryzner's index value (variations from 7.9 to 9.1 in the four-year period 1998-2001).

For the purpose of the present work, the single chemical analysis of hot water in region I was made and general physico-chemical parameters of water in region I are presented in Table 1 and its chemical composition in Table 2.

TABLE 1. PHYSICO-CHEMICAL PARAMETERS (REGION I)

pH(pH-metr WTW pH 330)	6,62
Total suspendedsolids	630,8 [mg/dm^3]
Mineralization M	826,3 [mg/dm^3]
Water hardness	441,4 [mg $CaCO_3$/dm^3]
Temporary hardness	320,5 [mg $CaCO_3$/dm^3]
γ_{25}	0,982 [mS/cm]
SiO_2	16,2 [mg/dm^3]
H_2SiO_3	21,06 [mg/dm^3]

TABLE 2. CHEMICAL COMPOSITION OF WATER (REGION I)

Ion	mg/dm^3	Ion	mg/dm^3
Na^+	37,60	Al^{3+}	0,0020
K^+	2,56	Cr^{3+}	0,00020
Li^+	0,014	Mo^{6+}	0,00084
Be^{2+}	<0,000020	V^{5+}	0,00970
Ca^{2+}	141,60	Zr^{4+}	0,0006
Mg^{2+}	21,41	Ti^{4+}	<0,005
Ba^{2+}	0,058	As^{3+}	0,00250
Sr^{2+}	0,421	Tl^{4+}	<0,000020
Fe^{2+}	0,055	W^{6+}	<0,002
Mn^{2+}	0,012	Cl^-	68,6
Zn^{2+}	2,36	Br^-	0,07
Cu^{2+}	0,030	J^-	<0,02
Ni^{2+}	0,00020	SO_4^{2-}	137,00
Co^{2+}	0,00077	HCO_3^{2-}	391,0
Pb^{2+}	0,00350	CO_3^{2-}	<0,5
Hg^{2+}	<0,0002	NO_2^-	<0,200
Cd^{2+}	0,00002	NO_3^-	0,90
Se^{2+}	<0,001	PO_4^{3-}	0,43
Sb^{3+}	0,00062	BO_3^{3-}	0,44

The chemical analysis was made by use of inductively coupled plasma mass spectrometer (ICP-MS) Perkin Elmer Elan 6100 DRC and inductively coupled plasma atomic emission spectrometer (ICP-AES) Perkin Elmer 7300 DV.

Calculated, on the basis of the above results, concentration ratio S_1value was equal 0.75 so according to EN 12502 (EuroNorm, 2005) pitting corrosion of zinc-coated steel pipes is possible.

Conclusions

The likelihood of zinc-coated steel piping failure due to the corrosion process depends on many factors such as operating conditions, characteristics of the metallic material (quality of zinc coating), design and construction and very strongly on the water chemistry. All above mentioned influencing factors should be taken into consideration in order to assess the corrosion likelihood of galvanized steel in water distribution system. Disregarding the water quality of local public-supplied water sources leeds to the failure of piping system described in this paper.

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COBRTI Instal, Polish Installation Technology Research& Development Centre, Zalecenia dla projektantów instalacji zimnej i ciepłej wody wodociągowej oraz wodnych instalacji ogrzewczych w zakresie wyboru i łączenia materiałów, uwzględniające agresywność korozyjną wód wodociągowych w 52 miastach w Polsce, 2002, (in Polish)

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