Failure Analysis of Welded Pipe in Water Supplies for Apartment

Jong Kwon Lee, Kyung Tae Hong*, Woon Seok Hwang, Yong Tae Koh***, and Yong Soo Park******

*Soonchunhyang University, *Korea Institute of Science &Technology, **KOGAS, ***Inha University, ****Yonsei University*

Galvanized Steel pipes have been widely used in industries and apartments. Unexpected early leakage has been found in an apartment. Tunneling corrosion or penetration was found in the water supply pipes. The chemical compositions of the pipes and properties of coating layer were evaluated. The pipes met the specification of KS D 3507. The cause of early failure was analyzed through the examination of macrostructures and microstructures. It was found that the pipes were failed by grooving corrosion, which resulted from galvanic corrosion of weld bead and matrix.

Keywords : *grooving corrosion, galvanized steel pipes, electrical resistance welding(ERW), metal flow, bond zone*

1. Introduction

Corrosion of pipeline causes red water and leakage which increases the economical losses by lessening service life. Early failure of pipelines was found in the apartment building at Daejon, Korea. The most recently constructed group of building among the three group of buildings have been suffered serious leakage of water line pipes since they have been constructed for three years. The details of corrosion of the group of buildings are presented in Table 1. As shown in Table 1, the pipes in the third group of the buildings were most severely corroded in spite of its short service period. It was found that all the pipes of three buildings met the specifications of 'Carbon Steel Pipes for Ordinary Piping'.[1] Those pipes, welded by same welding process, i.e., ERW(electrical resistance welding), were manufactured in two different companies. These are designated as 'A' and 'B'.

From the understanding of these facts, the causes of damaged pipes in the apartment could be deduced into two possibilities. One is the use of unsatisfactorily welded pipes due to the underheat during welding. The cold weld zone resulting from insufficient heat input acts as a crevice which enhance the corrosion in the zone.

Table 1. Constructed date of apartment and corroded state (as of April,1998)

	building constructed in	pipe state
1 group	Nov. 1986	red water
2 group	Dec. 1988	〃
3 group	Oct. 1989	penetration of pipes, leakage

The other possibility is the grooving corrosion which accelerated the corrosion, especially at the weld.[2)-7)]

In this paper, to investigate the cause of early leakage of the pipes, the two possibilities, i.e. insufficient welding and grooving corrosion, were thoroughly examined. Also, the shorter service life of B company was discussed. The most economical measures were recommended to prevent the water leakage.

2. Failure analysis

The failed pipes (nominal 15mm in diameter) were collected from those buildings. Some sound pipes were also collected as a reference.

2.1 Appearance

The appearance of the collected pipes were examined. In the pipes manufactured in A company, yellowish thin scale was formed over the galvanized layer. A slight or negligible corrosion was found at the weld inside the pipes. Comparing to the pipes, the pipes of B company, having leakage, were corroded severely. Some of them were penetrated(corroded competely away) through the pipe wall. The galvanized layer was rarely left inside the pipes. Thick reddish corrosion products covered the pipes and tubercules were scattered here and there. It should be noted that all the corrosion concentrated along the weld.

2.2 Chemical compositions

The chemical compositions of the pipes were analyzed and represented in Table 2. The sulfur content of A company was higher than that of B company, which were 0.013% and 0.009%, respectively. However, chemical compositions of those pipes met the previously mentioned specification.[1] Chemical compositions of the corrosion products were shown in Table 3, which shows that of A company have higher contents of P_2O_5 and Zn than B company.

Table 2. Chemical compositions of pipes(wt%)

	C	Si	Mn	P	S	Ni	Cu	Ca
A	0.046	0.019	0.36	0.021	0.013	0.013	0.018	<-0.001
B	0.019	0.012	0.23	0.014	0.009	0.011	0.017	<-0.001

Table 3. Chemical compositions of corrosion product(wt%)

	Si	Ca	Mn	Mg	Al	Fe	Zn	P_2O_5
A	0.44	1.41	0.11	0.12	1.13	12.5	28.1	7.81
B	0.3	0.32	0.16	0.02	1.14	61.2	0.65	0.1

2.3 Microstructures and weldability

To assess the weldability, the macrostructures and microstructures were examined. The width of bond zone of all the pipes were more than 40 ㎛, which is required width for sound pipes.[8] It is difficult to manufacture a ERW pipe with insufficient melting at the weld, since the whole surface was heated and squeezed out the melt in ERW. Also, in the case of cold welded pipes, it will be fractured in a straightening step. Moreover, it could have failed to pass the flattening test which is required in the specification. However, both of collected pipes, regardless of leaking, could pass those tests, that explains the different corrosion rate between two companys could not be ascribed to the inapproriate welding conditions.

It should be noted that the microstructures of weld and HAZ of the pipes which had through-wall leakages could not be made because all the weld were removed by corrosion.

2.4 Accelerated corrosion test

Accelerated corrosion tests were carried out to evaluate the grooving corrosion susceptibility of those pipes after removing remaining scales and corrosion products. The indices of grooving corrosion were obtained. The tests were performed by immersing in the 3% NaCl solutions at the potential of -500 mV vs. SCE(saturated calomel electrode) for 48 hrs. The grooving corrosion index can be represented as $\alpha = 1 + h_1/h_2$, where h1 is the depth of groove and h2 is the thickness of uniform corrosion attack .

In the experiment, the indices of the A company and B company were 2.12 and 2.07, respectively, which indicates that the corrosion resistances of those pipes are almost equivalent. However, the indices required for the corrosion resistant pipes according to KS D 3623 should be less than 1.2. Those obtained values could not meet the specification. Such high values of corrosion index could be ascribed to the high sulfur content in the those pipes, that were much higher than 0.005% as shown in Table 2.

2.5 Water analysis

Water quality was represented in Table 4. Since the water was not collected during the initial period of building and usage, the tap water of the present municipal water was analyzed assuming the quality was not changed. On the basis of the analysis, Langelier and Ryzner indices are calculated, which are -3.0 and 13, respectively. This is generally interpreted that Negative Langelier index and Ryzner index larger than 6 indicate corrosive characteristics of water.[9] Both indices showed the water used in the apartment was very easy to form scale.

Table 4. Result of water analysis

M alkalinity(mg$CaCO_3$/ℓ)	0.8
Ca hardness(mg$CaCO_3$/ℓ)	45.0
Mg hardness(mg$CaCO_3$/ℓ)	7.50
Cl^-(mg/ℓ)	5.94
SO_4^{2-}(mg/ℓ)	35.3
Fe(mg/ℓ)	0.36
Dissolved Oxygen(mg/ℓ)	2.7
Residue(mg/ℓ)	138

2.6 Characteristics of galvanized layer

Coating weight and uniformity of outer side were measured by the KS D 0201 and the results are shown in Table 5. Since the inner side of pipes underwent severe corrosion, the outer side of pipes with sound coating were tested. The coating weight of A and B company were 390 g/m^2 and 260 g/m^2, respectively. In the uniformity test, the pipe of A company was better than B company.

Table 5. Zinc coating weight and uniformity

Company	Deposition weight (g/m^2)	Uniformity test (number of dips)
A	392.3	13
B	259.5	7

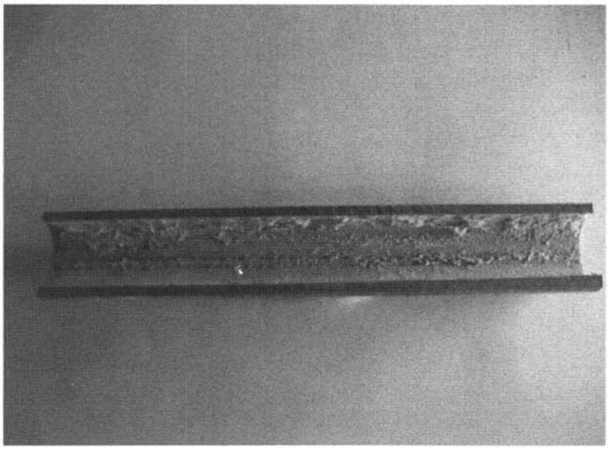


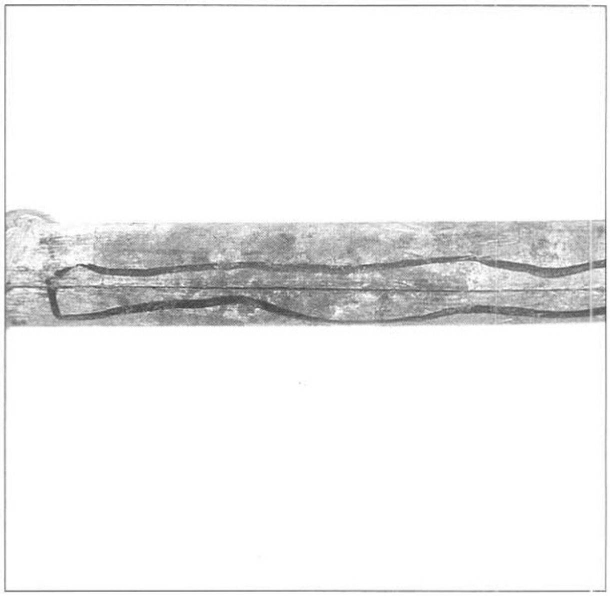
Fig. 1. Appearance of ERW steel pipe made in A company.

3. Discussion

From the understanding of these facts, the causes of damaged pipes in the apartment could be deduced into two possibilities. One is the use of unsatisfactorily welded pipes due to underheat. The cold weld zone resulting from insufficient heat input act as a crevice which enhanced the corrosion in the zone. In this case, welding defect acting like a crevice, resulting in the localized crevice corrosion at the weld bead. The resulted appearance after corrosion seemed that the penetration started from initial stage. The other is that a grooving corrosion, especially at the weld, could be a cause, as mentioned earlier. As a source of leakage, the former resulting from defect of pipe itself, while the latter from improper usage of pipes. Two possibilities mentioned above will be discussed and explained with the experimental results as follows.

If narrow gap was developed from welding defects, crevice corrosion could break out, followed by penetration of pipes. There are two kinds of welding defects in ERW, i.e. over-welding and cold-welding.[10] Cold-weld means low heat input during welding, leading to oxide residue at the interface and lowering toughness and strength. On the contrary, over-welding means that high heat input provided leading to partial disconnection or penetration defect.

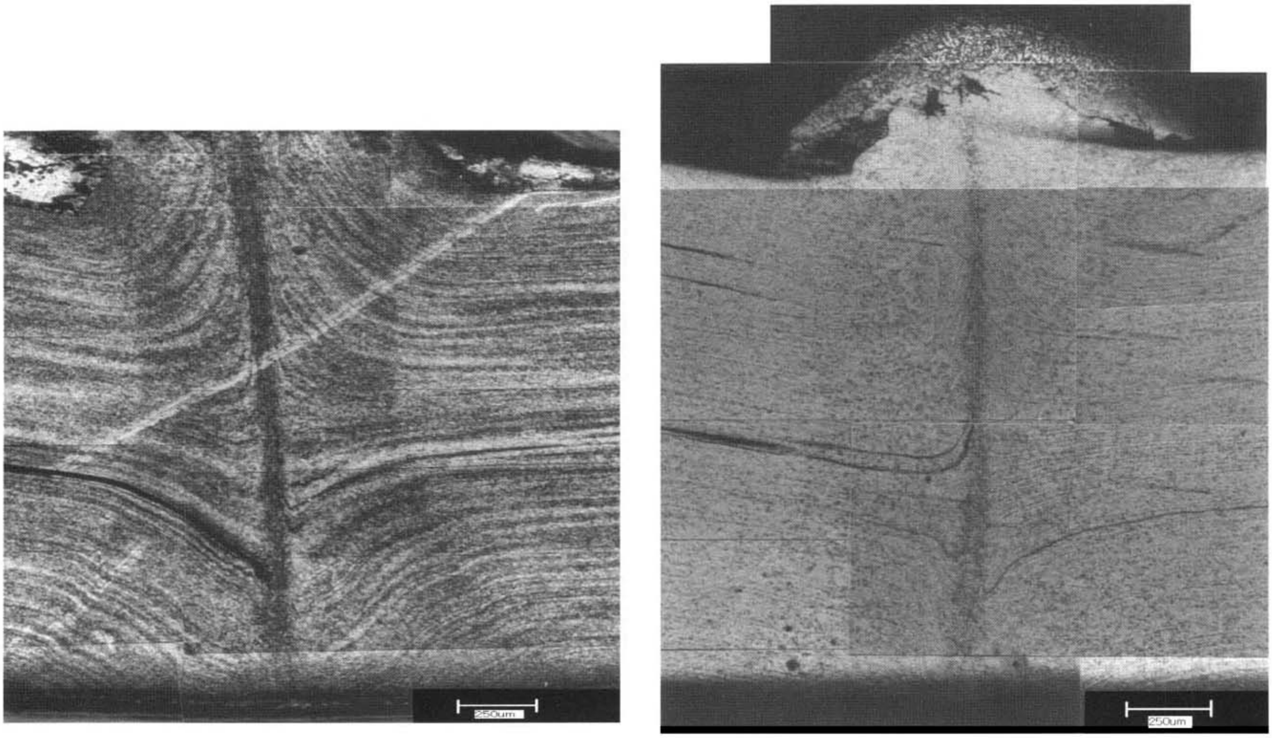
(a)



(b)

Fig. 2. Appearance of ERW steel pipe made in B company. (a) Inside scale, (b) Outward view

The bond layer of macrostructures could be the basis of determining the soundness of weld bead.[8] The optimal bond thickness could not be formed at improper weld temperature or heat input. In Fig. 3, macrostructures of A and B companies are shown. In the Figs, bond layers of A and B company are well developed. Therefore, the possibility of underweld can be excluded. The only possi-



(a) (b)

Fig. 3. Macrostructures of ERW Pipes a) A company, b) B company

bility which can cause the phenomenon is the grooving corrosion, i.e. electrochemically active weld bead can be preferentially dissolved compared to the matrix. The undesirable area ratio accelerated galvanic corrosion in this localized region. In this reason, not only weld bead but metal flow mark could be removed after corrosion in spite of proper bonding. As mentioned earlier, ERW pipes are susceptible to grooving corrosion. Especially, combination of highly corrodible water and chemical compositions with high sulfur above 0.005% make a condition to cause grooving corrosion. The cross section of pipes which suffer penetration or tunneling shows typical appearance of grooving corrosion. Moreover, the water quality in the pipes was analyzed to be corrosive. Therefore, the leakage could be ascribed to the combination of highly susceptible chemical compositions to grooving corrosion and corrosive water.

4. Corrosion prevention

The following prevention measures are suggested in order to extend the life of pipes or to repair it.

1) In the design or construction stage

More corrosion resistant materials are recommended. Pipes made of carbon steel produce red water or have short life. Generally, stainless steel, PVC, copper, and polyethylene are better materials to give the pipes a long life. PE(polyethylene) coated steel pipes are assessed as a more corrosion resistant material. The material manufactured by the KS D 3623 can be one of measure to extend life, but cannot inhibit red water or corrosion completely.

2) In the using pipes

Corrosion inhibitors including zinc and phosphate ions are effective to lessen corrosion damage of in-using pipes.[11]

3) In the damaged and penetrated pipes

Since changing all the damaged pipes are time-consuming and not economical, inside coating is the most effective measure. After removing corrosion product, lining such as epoxy resin is appropriate to prevent a furthur corrosion and red water in the apartment.

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