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Localized Corrosion of Zn-Plated Carbon Steel Used as a Fire Sprinkler Pipe

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The failure of a Zn-plated carbon steel pipe that served as a fire sprinkler was investigated in terms of the pipe's corrosion products. The pipes leaked through holes formed beneath the tubercles. The formation of oxygen concentration cell involves colonization of metal surface by aerobic bacteria or other slime formers, and anodic reaction beneath tubercle is accelerated by the presence of SRB, leading to the formation of hole beneath tubercle.

Keywords *: Zn-Plated Carbon Steel, Fire Sprinkler Pipe, Localized Corrosion*

1. Introduction

Localized corrosion of metal is very dangerous because of rapid penetration in small, discrete areas. In general, it is well known that localized corrosion is caused by filiform, crevice, pitting and biological corrosion.[1)] Localized corrosion has been observed on various metals, such as aluminum, magnesium and steel but, in particular, localized corrosion of carbon or stainless steel is of major concern because these materials have been extensively used in industrial constructions.

Pitting corrosion of stainless steels generally results from a combination of electrochemical and metallurgical factors, which includes the effect of alloying elements and the distribution of the non-metallic inclusions. V.Vignal *et al.*[2)] concluded from their work on the pitting corrosion of stainless steel that inclusions as cathodic site and the surrounding matrix as anodic site result in the formation of pitting corrosion. In contrast, Y.Tsutsumi *et al.*[3)] studied the corrosion mechanism of 304 stainless steel under a droplet of chloride solution. They reported that the pitting corrosion of 304 stainless steel was caused by the dissolution of inclusions (e.g., MnS).

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Since carbon steel has a relatively homogeneous microstructure when compared to stainless steel, corrosion of carbon steel appears to proceed by a different mechanism. According to Matsushima,[4)] it has been reported that localized corrosion in carbon steel usually occurs via the action of macro-galvanic cells. In macro-galvanic cells, the anodic areas are macroscopic, and are surrounded by or connected to a relatively large cathodic area, leading to localized corrosion of iron and steel.

As mentioned above, localized corrosion of carbon or stainless steel appears to proceeds via various mechanisms and depends on the corrosion environment, microstructure of the metals and the type of structure involved.

This study was performed to clarify the mechanism of localized corrosion of Zn-plated carbon steel that is used as a fire sprinkler pipe material.

2. Experimental

All specimens in this study were selected from a sample of KSD 3507 pipe that had served for 13 years as a fire sprinkler pipe. The specimen was cross-sectioned using a diamond saw and polished with sandpaper (#400 to #2000) and, finally, with diamond paste (1 μm). Afterwards, the cross-section was observed by an optical microscope.

To identify the corrosion products, the corrosion materials were carefully collected and characterized by a X-Ray Diffractometer (XRD, Rigaku, MX-UA). The impurity contents and microstructure of the corrosion products were investigated using a Field Emission Scanning Electron Microscope (FESEM, JEOL, JEM-2010) that had EDS (Energy Dispersive Spectroscopy) capabilities.

3. Results & discussion

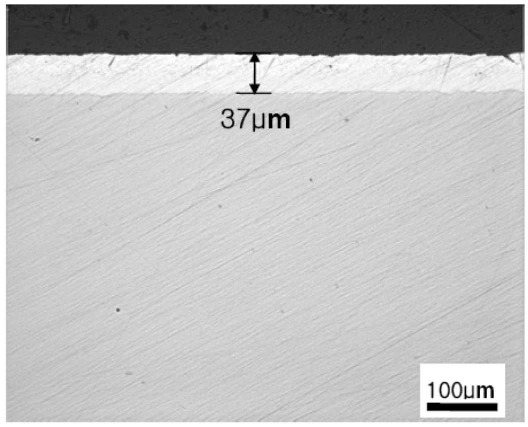
Figures 1(a) and (b) show typical cross-sections of a fire sprinkler pipe. The external and internal surfaces of the pipe were Zn-plated for corrosion protection by a sacrificial anode, and the thicknesses of the Zn layers outside and inside of pipe were approximately 37 and 18 µm, respectively, as shown in Figs. 1(a) and (b).

Figures 2 (a), (c), (e) and (g) show samples obtained from various positions in the building. The corrosion products were carefully collected from the internal surfaces of pipes, and the XRD analyses were performed to identify the corrosion products formed at each pipe. ZnO and Fe_2O_3 were detected in the corrosion products shown in Fig. 2 (a), ZnO in Fig. 2 (c), Fe_2O_3, ZnO, $CaCO_3$ and $ZnFe_2O_4$ in Fig. 2 (e), and Fe_3O_4 in Fig 2 (g) (see Fig. 2 (b), (d), (f) and (h) for XRD analysis results). Although various compounds were identified, the major corrosion products were Fe_2O_3 (brown), Fe_3O_4 (black) and ZnO (white). The most internal surface of pipe is covered with ZnO, and in some regions, brown or black colors of tubercles are observed as shown in Fig. 1(a) and (e).

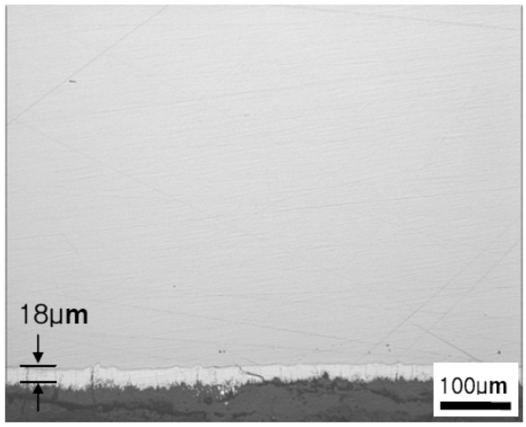
The degree of corrosion inside of pipes covered with ZnO or tubercles is compared. Figure 3(a) shows tubercles formed on the internal surface of the pipe. To investigate the degree of corrosion near the tubercles, the cross-section was observed as shown in Fig. 3(b). The thickness of the Zn layer in approaching to tubercles decreases due to a loss of the Zn layer and localized corrosion occurred at the tubercles (as shown in Fig. 3(b)). To further observe the localized corrosion beneath the tubercles, the tubercles were physically removed, and the tubercle-removed region was observed using an optical microscope. Figure 3(c) (dotted circle) shows the hole formed beneath the tubercle that causes the water leakage of a sprinkler. In contrast, localized corrosion in pipe covered with ZnO does not occur although the thickness of the Zn layer of the pipe decreases to < 10 µm as shown in Fig. 4. From this fact, it is concluded that the failure of a sprinkler pipe is attributed to the formation of tubercles, in particular, the hole formed beneath a tubercle.

It has been well known that tubercles are grown by an oxygen concentration cell.[5)-7)] The oxygen concentration cell can be initiated by microbial colony or deposits that shield a small area from the dissolved oxygen in the water. Babakr et al.,[5)] investigated the tuberculation corrosion in pipeline. They reported that ferrous hydroxide can be formed on steel or cast iron when placed in oxygenated water near neutral pH and this corrosion product shield the metal surface underneath from the oxygenated water, resulting in the formation of oxygen concentration cell. On the other hand, according to Ringas et al.,[6)] the oxygen concentration cell can be formed by aerobic bacteria that colonize a metal surface. Aerobic bacteria colonize a metal surface first. As they grow, the oxygen concentration cell is set up between the region beneath the colony (low oxygen potential) and the periphery of the colony (high oxygen potential).

In this study, it is important to clarify the cause for the formation of oxygen concentration cell. Figure 5 shows a large amount of slime observed inside of pipes. It has been well known that the slime is formed by oxy-



(a)



(b)

Fig. 1. (a) Cross-section near external surface of pipe and (b) cross-section near internal surface of pipe.

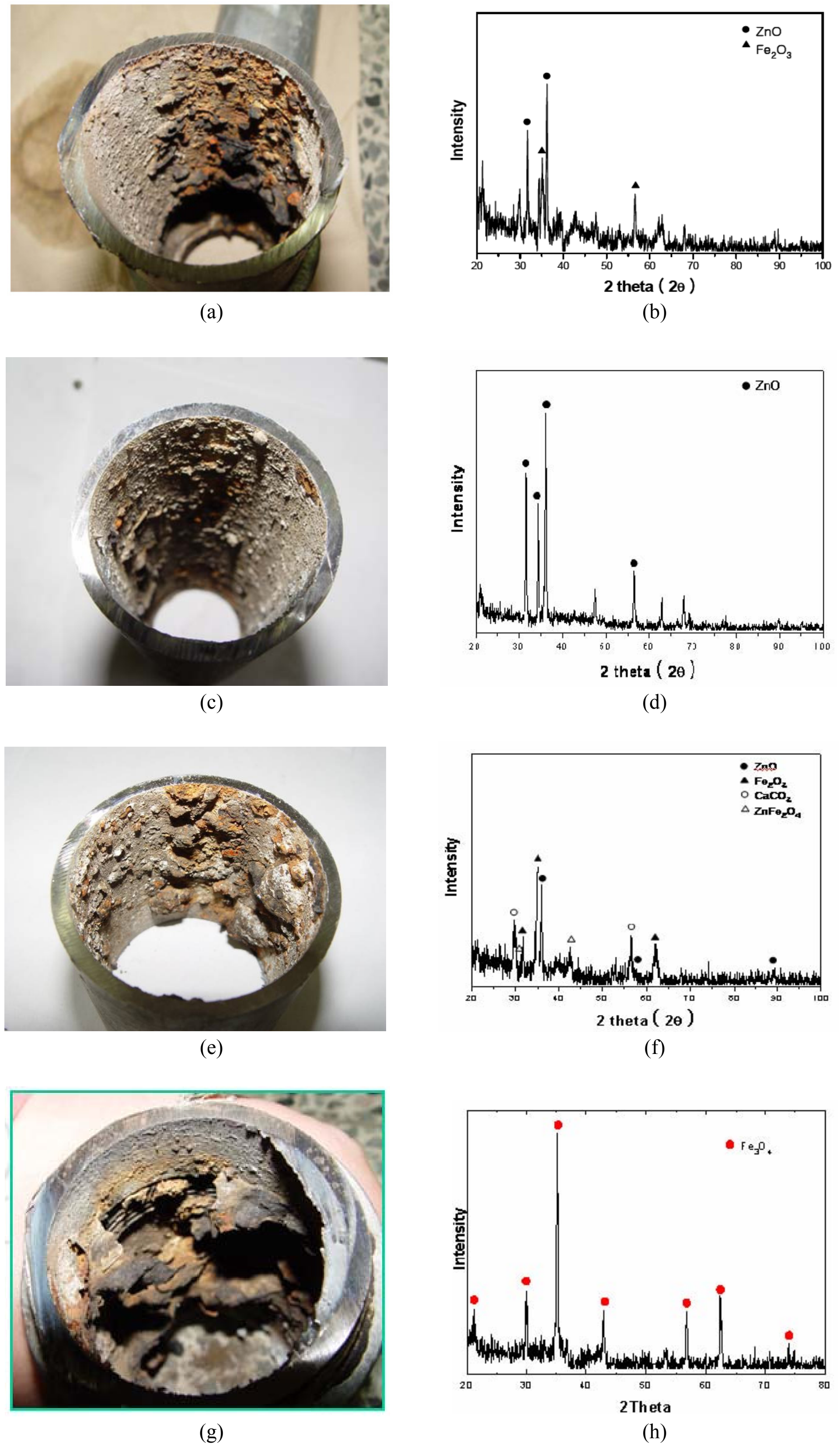
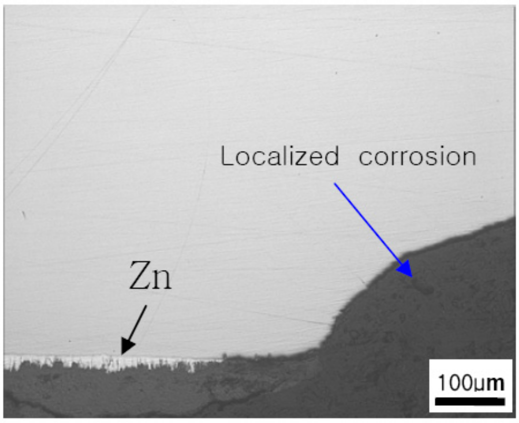


Fig. 2. XRD patterns for various corrosion products observed inside of pipe.

(a)

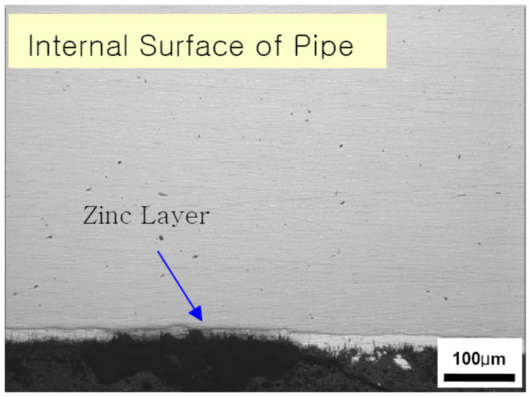


(b)

(c)

Fig. 3. (a) macroscopic view for cross-section, (b) cross-section near a tubercle in fire sprinkler pipe that was in use for 13 years and (c) hole observed beneath a tubercle after that tubercle was physically removed.

(a)

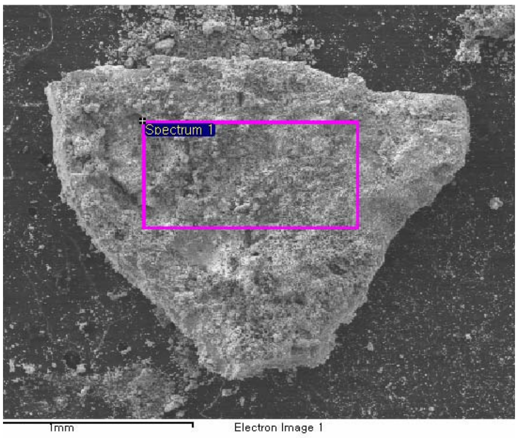


(b)

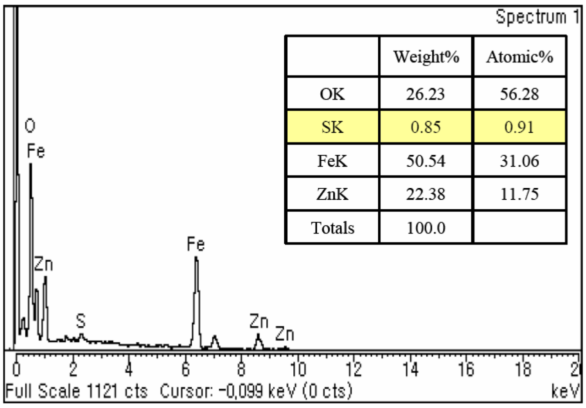
Fig. 4. (a) Macroscopic view and (b) cross-section of a pipe covered with ZnO.

Fig. 5. Slime formed inside of pipe.

gen-consuming aerobic bacteria or other slime formers.[6,7] Thus, the presence of the slime indicates that the formation of oxygen concentration cell in this study involves colonization of metal surface by aerobic bacteria or other slime formers. Figure 6 shows the EDS analysis to confirm the presence of impurity elements in corrosion products. High sulfur contents were detected, as shown in Fig. 6(b), where we interpret this as resulting from the byproducts of the corrosion reactions. The possible corrosion reaction



(a)



	Weight%	Atomic%
OK	26.23	56.28
SK	0.85	0.91
FeK	50.54	31.06
ZnK	22.38	11.75
Totals	100.0	

(b)

Fig. 6. (a) FESEM micrograph of the corrosion product and (b) EDS analysis of the corrosion products shown in (a).

is the formation of iron sulfide or hydrogen sulfide via sulfur-reducing bacteria (SRB).[6)-8)] Considering the presence of slime on the internal surface of pipe, sulfur in corrosion products and tubercles consisting of iron oxides, it is concluded that the failure of a fire sprinkler pipe is attributed to the formation of oxygen concentration cell by aerobic bacteria or other slime formers and corrosion acceleration by SRB.

4. Conclusions

The present study addresses the failure mechanism of a fire sprinkler pipe (KSD 3507) serviced for 13 years. The water leakage of the fire sprinkler is caused by the hole formed beneath a tubercle which is grown by oxygen concentration cell. The oxygen concentration cell is formed by aerobic bacteria or other slime formers, and the localized corrosion below tubercles is accelerated by SRB, resulting in the formation of hole beneath tubercle.

Acknowledgement

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