Research on the Corrosion of Sewer System Pipelines from Domestic Wastewater

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Abstract

This paper studies the corrosion mechanism of domestic wastewater on concrete or reinforced concrete pipelines by analyzing the sewerage sampled in different sites and at different times in the sewer pipeline in Chongqing, Peoples Republic of China (P.R. China). The main factors affecting the durability of the concrete pipeline are corrosion of the reinforcement in the concrete caused by hydrogen sulfide and acidic wastewater. Some preventive measures for protecting the concrete and reinforced concrete pipeline are also proposed.

Introduction

Most of the pipelines for the sewer system in Peoples Republic of China (P.R. China) are made of concrete or reinforced concrete. During the lifetime of the sewer pipeline, they experience various types of deterioration or damage caused by corrosion from sewerage, stress in the pipe from the weight of the soil and erosion from the wastewater in the pipelines. The deterioration of the pipe shortens the life of the pipe and results in wastewater leaking from the pipes and polluting the environment. Because of the necessity for long service life in the sewer system pipelines, generally more than 50 years, and the difficulties associated with inspection and repair, it is beneficial to do research on the corrosion of sewerage concrete pipe.

The corrosion phenomena of the sewer pipeline used for almost 30 years in Chongqing, China is investigated, and the main corrosive materials and their corrosive mechanism on the concrete pipeline, such as chemical corrosive reaction on the concrete and electrochemical corrosive reaction on the reinforcement of concrete, are

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analyzed. Some preventive measures for the concrete or reinforced concrete sewer pipeline are also proposed.

Corrosion Situation and Components of Domestic Wastewater

The source of the domestic wastewater in the urban sewer pipeline is that of the inhabitants' daily life, while the quantity of flow, the components and the consistency of sewerage are related to the living status of the inhabitants. The advantage of analyzing the corrosion of domestic wastewater is that the quantity of flow, the components and the consistency of it are relatively stable and constant.

The inspection of several Chonaqing sewerage pipes and manholes revealed some cracks and leaks indicating corrosion of the pipe. Corrosion at the pipe joints was more severe than that in the pipe. The components and their consistency in the sewerage, sampled at two different sites and at three different periods during the day are shown in Table 1. The data of Site 2 is taken from the paper prepared by Zhou (2002). The data reveal that the main components of sewerage in Chongqing that cause corrosion of concrete pipe are: pH, sulfide, sulfate, ammonia, sodium, magnesium, and chloride. The concentrations of the components are different in the two regions of the City.

Table 1. Main Components of Sewerage in Chongqing

Site	Period	pH	Suspension mg/L	Sulfide mg/L	Na^+ mg/L	Mg^{2+} mg/L	Cl^- mg/L	SO_4^{2-} mg/L	NH_4^-	CO_2 mg/L
1	1	7.67	2.78×10^2	0.523	6.70	1.10	5.5	None	5.0	No
	2	7.59	2.92×10^2	0.685	5.60	1.10	4.5		3.00	
	3	7.71	2.48×10^2	0.621	4.90	1.00	4.9		2.20	
2	1	7.10	None	0.369	42.3	10.6	64.2	38.6	21.8	9.2
	2	7.20		0.702	51.2	10.2	75.5	4.5	36.2	10.3
	3	7.15		0.589	59.7	10.2	69.8	56.8	31.3	14.7

Corrosion Mechanism of Sewerage to the Concrete Pipeline

Concrete is a porous mixture of Portland cement, water, sand and stone or crushed gravel. The water and cement form a cement paste, which acts as the structural component of concrete, in which the aggregates made up of sand and stone or crushed gravel are mixed. The main ingredients of the cement paste are calcium silicate or calcium silicate paste, calcium hydroxide ($Ca(OH)_2$), and calcium aluminate ($CaO{\cdot}Al_2O_3{\cdot}6H_2O$). The latter two ingredients of cement paste are the inherent factors leading to the corrosion of concrete. The porosity of the paste or the interface between the paste and aggregates, and in the surface of aggregates, is the weakest portions of the concrete. These weaknesses make concrete poor in tensile, shearing and fatigue load to some extent, as well as providing channels for the migration of corrosive material and moisture into concrete. If the corrosive material has a chemical or electrochemical reaction with the ingredients of concrete, such as $Ca(OH)_2$, and $CaO{\cdot}Al_2O_3{\cdot}6H_2O$, or corrodes the reinforcement in concrete, the result is to destroy the structural function of cement paste, and the corrosion will result in serious damage to concrete pipe.

The most common corrosive cases of domestic wastewater on concrete or reinforced concrete pipeline are analyzed as follows.

Dissolution Corrosion of Acid Waste Water. If calcium hydroxide, which is one of the products of the hydration of cement, reacts with CO_2 dissolved in the sewerage, it will result in dissolved $Ca(HCO_3)_2$ and cause the loss of the calcium hydroxide and reduce the pH of the concrete. The corrosion of the concrete will be accelerated by erosion of the concrete caused by the flow of wastewater. When the concentration of $Ca(OH)_2$ in concrete is less than the critical value, it will result in a constant dissolving of the compounds of the cement paste.

If the water is hard, or the concentration of HCO_3^{2-} is relatively large, the result of the reaction between HCO_3^{2-} and $Ca(OH)_2$, which is insoluble $Ca(CO_3)_2$, will prevent the loss of $Ca(OH)_2$.

Table 1 indicates that the concentration of CO_2 in the domestic wastewater is not more than 40mg/L, so the corrosive effects of acids in the wastewater will not occur in the early period of the service life of sewer system pipelines, but corrosion will develop slowly over the expected lifetime.

Soluble Corrosion. The soluble corrosion is caused by the attack of acids, such as sulfuric acid and hydrochloric acid, and metallic cations, such as magnesium and sodium, on concrete. Considering the difference in effect and corrosion products, the soluble corrosion can be divided into several types such as soluble corrosion by acids, sulfurated hydrogen, and by metallic cations.

Soluble corrosion by acid is caused by the reaction between H^+, which is the ionization of acids such as HCl, H_2SO_4, or HNO_3 in a solution of porous concrete and the hydrated cement, that results in the soluble calcium salt and aluminate, as shown in the reactions given as Equations (1) and (2).

$$2H^+ + Ca(OH)_2 \rightarrow Ca^{2+} + 2H_2O \quad (1)$$

$$mCaOHSiO_2 + mH^+ + (n\text{-}0.5m)H_2O \rightarrow mCa^{2+} + nSi(OH)_2 \quad (2)$$

Generally, when pH<4, corrosion from sewerage is significant on concrete. In actual practice the corrosion of concrete from domestic wastewater is minor, since its pH is between 6 and 9 as shown in Table 1.

The significant amount of organic materials in the wastewater will react reductively with SO_4^{2-} and $Ca(OH)_2$ in anaerobic conditions to produce soluble $Ca(OH)_2$, as shown in Equations (3) to (8). So the loss of $Ca(OH)_2$, which is the one of the essential components of hydrated cement, will cause the deterioration of concrete. According to the data shown in Table 1, the soluble corrosion of sulfurated hydrogen is an important factor of the degradation of concrete pipe.

$$SO_4^{2-} + \text{Organic Material} \rightarrow S^{2-}1^{2+} + H_2O + CO_2 \quad (3)$$

$$S^{2-} + 2H^+ \rightarrow H_2S \quad (4)$$

$$H_2S \rightarrow H^+ + HS^- \rightarrow 2H^+ + S^{2-} \quad (5)$$

$$CaCO_3 + H_2S \rightarrow Ca(HCO_3)_2 + CaS \quad (6)$$
$$Ca(OH)_2 + H_2S \rightarrow CaS + H_2O \quad (7)$$
$$CaS + H_2S \rightarrow Ca(HS)_2 \quad (8)$$

The other type of soluble corrosion of concrete is that of metallic salt, which results from the exchange between metallic cation of salt in the corrosive liquid and that of cement paste, to make the concrete alkalescence with the product of soluble and non-viscous compound, and result in structural damage to the cement paste. It can be seen in Table 1 that the corrosion by salt will not be the main cause of corrosion to domestic wastewater pipes because concentration of the metallic cations is low.

Expansion Damage

The degradation of concrete caused by its internal expansion is produced from the of chemical reactions between sulfate in wastewater and hydrated cement, such as $Ca(OH)_2$ and $CaO{\cdot}Al_2O_3{\cdot}6H_2O$, as shown in Equation (9). These products of chemical reactions can have different properties, but normally their specific volume is 1.5 times larger than that of the original paste. The result is expansion stress which will cause the stress concentration and the cracking of concrete.

$$3Ca(OH)_2 + 3CaO{\cdot}Al_2O_3{\cdot}6H_2O + 3SO_4^{2-} + 25H_2O \rightarrow 3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}31H_2O + 6OH^- \quad (9)$$

The corrosive effect of the sulfate on concrete pipe is heightened with the presence of it in wastewater. The degradation of concrete caused by the expansion is slow because of the low concentration of sulfate in sewerage as shown in Table 1. The concentration varies from 4.5mg/L to 37.6mg/L.

Crystal damage is seldom found in sewer concrete pipelines because of the almost constant humidity and temperature of the concrete in a buried condition.

Corrosion of Reinforcement

The pH of fresh concrete is about 12 to 14. A passivity layer is formed on the surface of steel reinforcement to prevent the further corrosion of the steel. When the concrete cover is carbonated by the chemical change of CO_2, water, and cement paste, the environment of rebar turns to alkalescence. The passive effects of cement are not destroyed until the initial layer of carbonation reaches the surface of the steel, also called rebar depassivation. The passive rebar begins to corrode with a complex electrochemical change after the rebar is depassivated in the presence of moisture, oxygen, and so on.

Another significant factor for steel corrosion is the presence of chlorides. Chlorides in wastewater will migrate into the concrete through the pores or cracks, and adhere to the surface of passive steel. Because of the flaw of the rebar, chlorides will migrate into the rebar further and remove the passivation. During this process, the chlorides act as carrier and activator to push the steel corrosion rapidly if no effective maintenance measure is adopted.

The degradation of concrete by the corrosion of its reinforcement is clearly a very complex reaction that involves multiple causes and effects. From the mechanical point of view, it consists of a loss of the rebar cross-section as the steel is transformed into rust. The specific volume of these products of corrosion is normally 2 to 4 times greater than new steel. The result is a dilatation of the bar and consequential cracking of the surrounding concrete, deterioration of the bond between the concrete and rebar, and a reduction in the structural capacity of the concrete.

It can be seen in Table 1 that the concentration of CO_2 and chlorides in the sewerage of Chongqing is not large. Considering the small thickness of the concrete cover (the smallest is 10mm), the small diameter of rebar (the smallest is 3mm), which is usually a hoop of plain bar, and the difficulty in inspection and repairing the pipe during the long service life; corrosion of the rebar is an essential factor in the durability of concrete pipe, with the viewpoint sustained by inspecting the phenomena of corrosion of sewerage pipeline in Chongqing.

Conclusions

The above results are not final because they are part of a wider research project that aims at a better estimation of the remaining service life of concrete pipelines. In addition, the goal is to determine the optimum period for inspection and repairing the corroded pipelines. In this paper, preliminary results are presented, based on the investigation of the causes of corrosion in concrete pipe and analyzing the corrosion reactions from domestic wastewater. They are:

1. The effect on the concrete pipe of urban domestic wastewater is during the long period of their service life instead of short-term effects. The dominant factors are the corrosion of reinforcement, the expansion damage due to sulfate, and the soluble corrosion of acid wastewater. The concentrations and components of the sewerage vary in different regions of the city.

2. In order to improve the durability of sewerage concrete pipe to resist the corrosive effects of wastewater, it is proposed to increase the density and thickness of the concrete layers or to utilize some corrosion-resistant pipes such as those made of PVC. This may increase the cost.

3. The concrete pipe is subjected to the load of soil above it and water going through it, in addition to the types of corrosion described above. The research on the combined effects of load stress and corrosion of concrete pipe will be presented in another paper.

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