Assessment of Concrete Corrosion by Carbonic Acid

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Abstract

An assessment of the corrosion and deterioration of concrete in environment (sewage facility) is proposed from the experimental results. Over the periods, changes to the roughened surfaces, mass change and carbonation (neutralization) depth were observed. And a relation between carbonation depth and mass loss of concrete in this water-processing environment was shown a good correlation.

Key words: concrete corrosion, free carbon dioxide, mass change, maximum load, carbonation depth

1. Introduction

This report is consisted with the previous reports and outlined from them [1] – [4].

The corrosion and deterioration of concrete structure under various environment varies with load, environmental condition, and other physiochemical factors. The deterioration phenomenon in this case is corrosion of concrete in a water- processing environment in a sewerage facility using an oxygen aeration activated sludge process [5].

Generally, the main cause of corrosion of concrete in an environment like sewage pipes is sulfuric acid [6]-[8]. However, results of this case showed the main cause of the concrete corrosion was erosive free carbon dioxide [9][10].

The main focus of this study was nondestructively to measure the degree of deterioration under the differing conditions of each environment in a sewerage facility in long-term exposure test [9]. In destructively, some of the test specimens were examined physically and were also analyzed chemically after 13- or 14-year period. This report is mainly discussed results from physical examination.

From these results of examining and analysing in this deterioration case, this report proposes the assessment and method of estimating for the corrosion and deterioration of concrete under the various environmental conditions.

2. Experimental Outline

2.1 Environment

The immersion environment of the test specimens was selected the trough of the final sedimentation tank in the oxygen treatment process.

For comparison, other immersion locations, such as the final sedimentation tank of the oxygen process and the trough in the air treatment process, were also selected.

2.2 Specimen Factors

The mix proportions of test specimens are shown in **Table 1**. Ordinary Portland cement was used and aggregates were used with sea sand and crushed stone.

The water-cement ratios (w/c) of 50, 55, and 60 %, and two unit cement weights of 300 and 330 kg/m^3 were chosen. The slump and air volume of all concrete specimens were, respectively, 8±1 cm and 4±0.5 %. In addition to these six types of concrete, specimens with lining ("coating with resin or mortar"), flow and polymer- cement concrete were also prepared. The basic mix proportions of the base concrete for the lining specification, unit cement weight and w/c, were respectively 330 kg/m^3 and 55 %. The slump of flow concrete was 18±1 cm. The polymer cement ratio of the polymer-cement concrete was set at 10 % and the w/c at 51 %.

For the lining, two kinds of resin and one kind of mortar were used. Each epoxy resin and tar epoxy resin were used as resin for lining. The thickness of the resin lining applied to the concrete was 400-600 μm or 600-1000 μm. Furthermore, there was a possibility that a lining primer would impregnate the concrete and change its physical properties. Therefore, no primer was used. The mortar for the lining was made with a 34 %-w/c; sand : cement = 2 : 1; and a flow value of 183.

Three test specimens were prepared for each factor.

The specimens size were 100x100x400 mm for immersing in the final tank of the oxygen process and were 50x100x400 mm for immersing in the trough of the oxygen and air process.

All test specimens were cured in water for two weeks and then under air conditions for two weeks. Test specimens were subjected to an immersion test after which the concrete surface was coated with the lining or subjected to other forms.

2.3 Test Items

The 100x100x400 mm test specimens were placed in a stainless steel net and immersed in the sedimentation tank. There was a possibility that the 50x100x400 mm test specimens immersed in the trough could be washed away by the water flow.

Therefore, they were attached by metal fittings to a stainless steel chain stretched in the flow direction of the trough. All test specimens were measured after being raised from their location and washed. Each test specimen was also inspected visually in its immersion location (roughness of surface, swelling, peelings and cracks in the lining layer), change in mass and measurement of the dynamic modulus of elasticity.

One test specimen for each factor was subjected to a flexural test. After the test specimen had been ruptured by the flexural test, it was subjected to visual section inspection and measurement of carbonation depth (phenolphthalein method), water absorption, pore distribution (mercury intrusion method) as well as electron probe microanalysis, X-ray powder diffraction analysis, and X-ray fluorescence analysis.

In this report, main discussions are results of mass loss, maximum load by flexural test, and carbonation depth. The other results are discussed according to necessity concisely.

Table 1 Main factors of mix proportions

Kind of concrete	Non-lining concrete						Lining concrete					Non-lining concrete	
	conventional concrete						Epoxy		Tar-epoxy		Mortar	Flow	Polymer-cement
Specimen No.	1	2	3	4	5	6	7(1)*1	7(3)*2	8(1)*1	8(3)*2	9*3	10	11
Water-cement ratio w/c (%)	50	55	60	50	55	60	55	55	55	55	55	55	51
Unit wt. of cement (kg/m³)	300			330			330					330	
Sand percentage s/a (%)	44			42			42					48	42

*1: one time coating (lining thickness of 400-600 μm)
*2: three times coating (lining thickness of 600-1000 μm)
*3: mortar coating (lining thickness of 10 mm)

3. Results

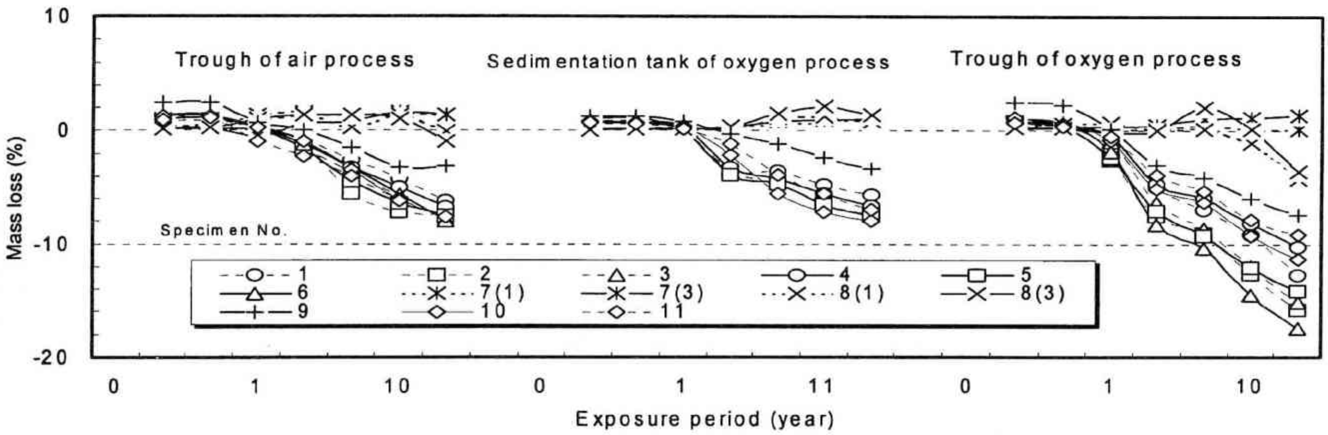

Fig. 1 Changes in mass of specimens in each processing system

3.1 Mass Loss

Changes in mass loss (**Fig. 1**), visual inspection, and relative dynamic modulus of elasticity for all test specimens were observed with exposure period (13- or 14-year). Differences in environment led to variations in the degree of corrosion, with the most severe suffered by specimens in the trough of the oxygen system. Looking at mix proportion factors in the case of non-lining concrete, the mass loss at a w/c of 55 % and 60 % was larger than that at 50 %. Therefore, a low w/c is one effective way to control corrosion. Also effective is to increase the unit cement weight. Still another is treating the concrete surface with a lining. Almost no corrosion was observed for test specimens with epoxy-resin lining even after more than 10 years.

3.2 Maximum Load By Flexural (Bending) Test

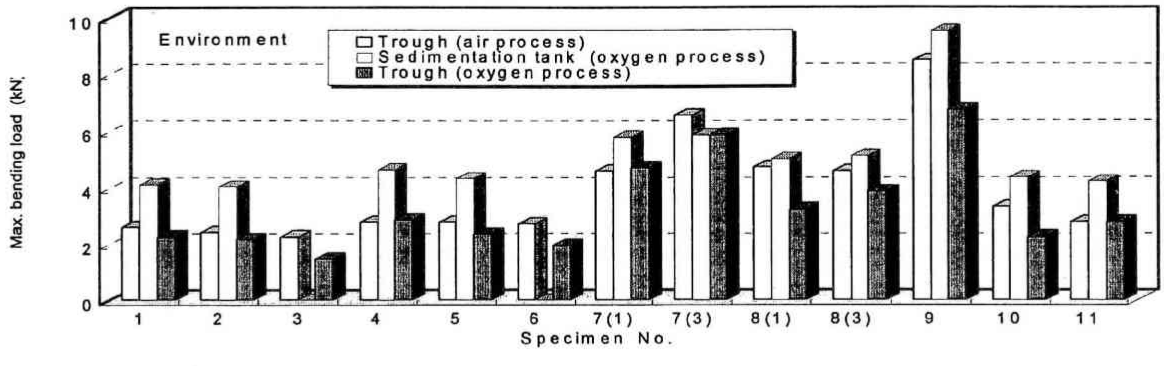

Fig.2 Maximum load by flexural test

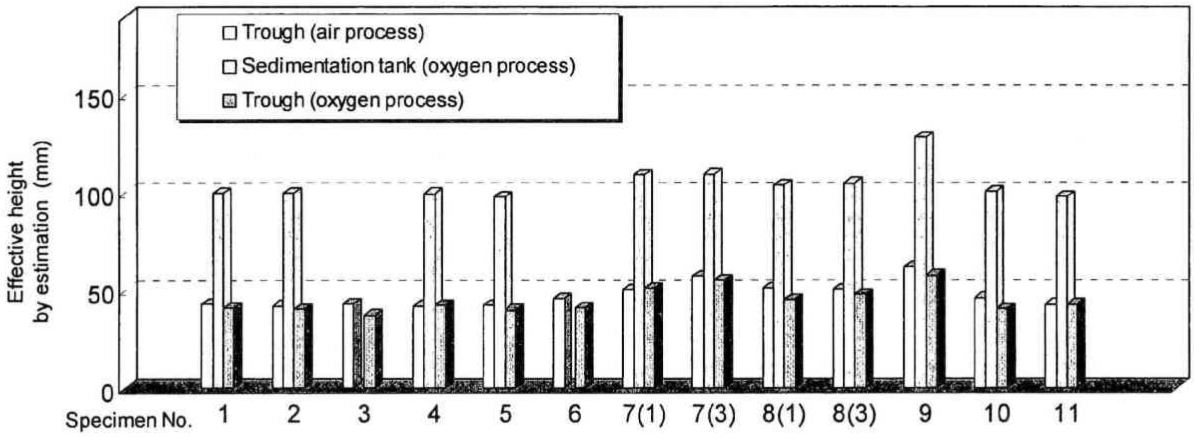

Fig. 3 Estimation of effective section height by bending maximum load

The results are shown in **Fig. 2**. The section height of the test specimens in the sedimentation tank of the oxygen process was twice that of the test specimens in other environments. Considering this, the measured values of bending strength for test specimens in the sedimentation tank of the oxygen process would be 4 times greater. Therefore, these maximum loads are multiplied by a factor of 1/4 in **Fig. 2**. Since most of the measured values are from a single test specimen only, a considerable variance is conceivable. However, as a whole, the maximum load determined from bending tests on test specimens in the trough of the oxygen process is lower than that in the trough of the air process. Therefore, the results clearly show the differences between the influence of the environment in the trough of the air and oxygen process. Thus, these test results suggest that a test specimen in a particular environment is influenced by the unit cement weight, water-cement ratio, and lining on the surface.

Therefore, durability increases with a high unit cement weight, low water-cement ratio, and a lining. The max. bending load depend on mix proportion factors and the system environment.

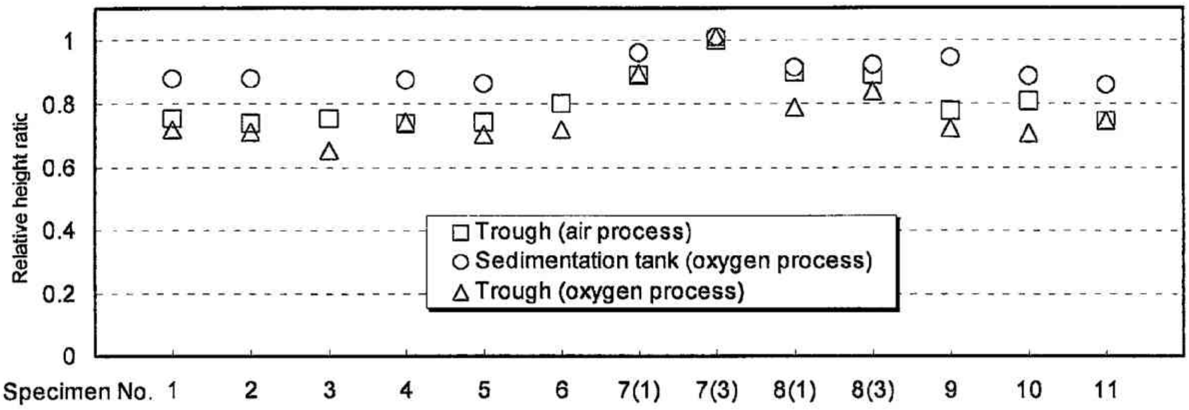

Fig. 4 Relative height ratio (effective height of epoxy lining concrete:1)

3.3 Effective Section D

The effective section of d estimated using below assumption is shown in **Fig. 3**.

This effective section was estimated using the calculation formula (1) for the bending strength based on the compression test results at the start of exposure.

$$f_b = \frac{PL}{bd^2} \qquad (1)$$

where, P is the maximum load on the test specimen, L is the span, b is the width of failed section, and d is the height of the failed section.

Estimation of the effective section was based on the following relationship. The f_b used was 1/7 of the value of the 28-day compressive strength at the time the test specimen was cast. Comparison of the estimated values showed the effective section of the non-lining test specimens to decrease more than the epoxy resin lining ones. Also, looking at the difference in environments, the effective section of the oxygen process specimens decreased more than that of the air process specimens.

If the effective section of the resin lining specimen estimated to be larger than the standard value before immersion was taken as equal to the standard value (lining specimen by three times coating with resin: 1), the ratio of the effective section of each test specimen would be as shown in **Fig. 4**.

However, the estimated effective section was calculated from the standard value of the bending strength of the concrete based on the compressive strength for the compressive test specimen cured for 28 days. Therefore, the estimated effective section may have been too large. Also, the d value of the lining test specimens shows a larger value in **Fig. 3** than the standard value, may have been possible the influence by the lining.

3.4 Carbonation Depth

The section of specimen by (flexural) tested was observed to have three regions from the outside to inward. The outside periphery of a few to 10 mm was a faint brown, the next about 1 mm was white, and the innermost was grey. Spraying with phenolphthalein (1%) solution, the innermost grey portion changed to red while the outer brown and white sections did not change. Therefore, the outer brown and white regions had undergone carbonation while the inner section had not. The carbonation depth can be compared if the specimen is not damaged by chipping. However, the degree of erosion of the cross section differs with test specimen and it is difficult to compare carbonation depths. Carbonation depth was estimated to save extent from the initial face of specimen before testing.

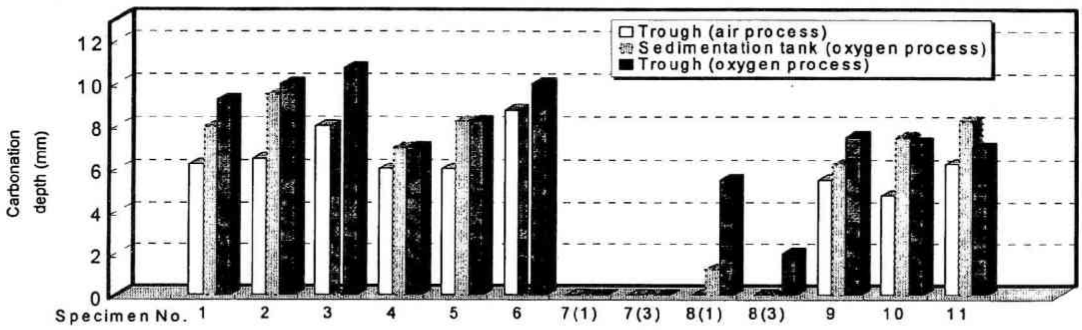

Fig. 5 Mean value of carbonation depth

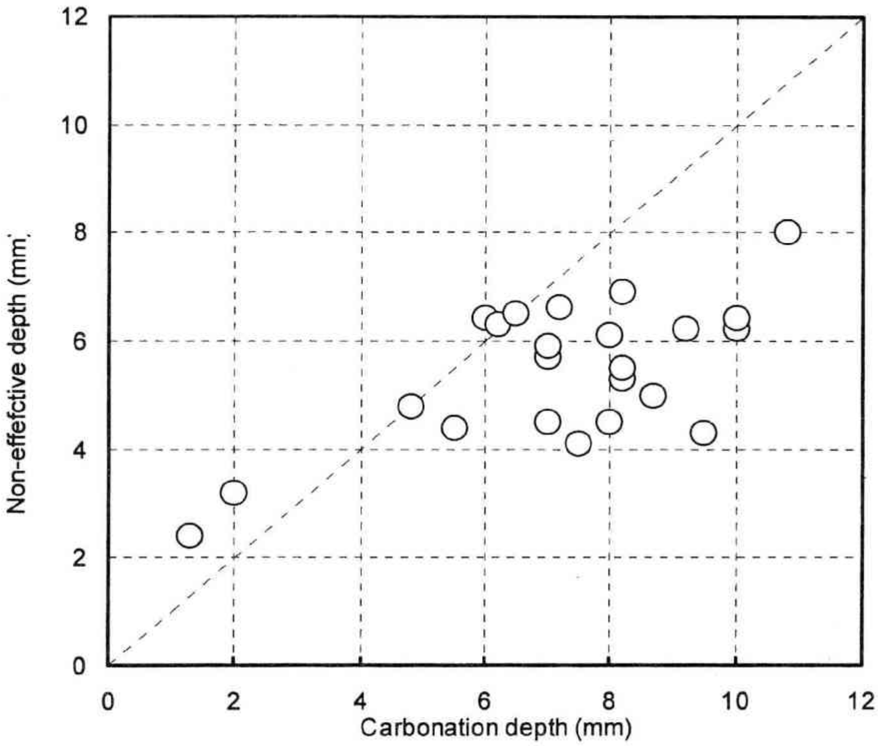

Fig. 6 Relationship between carbonation depth and non-effective depth

All conventional (specimen No.: 1-6), flow (No.: 10) and polymer-cement (No.: 11) concrete specimens showed carbonation depths of about 4 mm to 10 mm, while most the lining specimens (No.:7(1),7(3)) showed no carbonation, as can be seen from **Fig. 5**.

Also, differences were apparent according to the type of concrete and the environment. Therefore, the non-effective depth was taken to be half the height of the section (the standard section) before corrosion minus the height of the estimated effective section in **Fig. 3**. Comparing the non-effective depth and carbonation depth showed the latter to be larger, as can be seen in **Fig. 6**.

Thus, the part of carbonation region contributes to the mechanical performance. However, as mentioned above, if the effective section of the resin lining specimen is assumed to be the basic effective section, the section of each non-lining test specimen decreases, and non-effective depth approaches the carbonation depth.

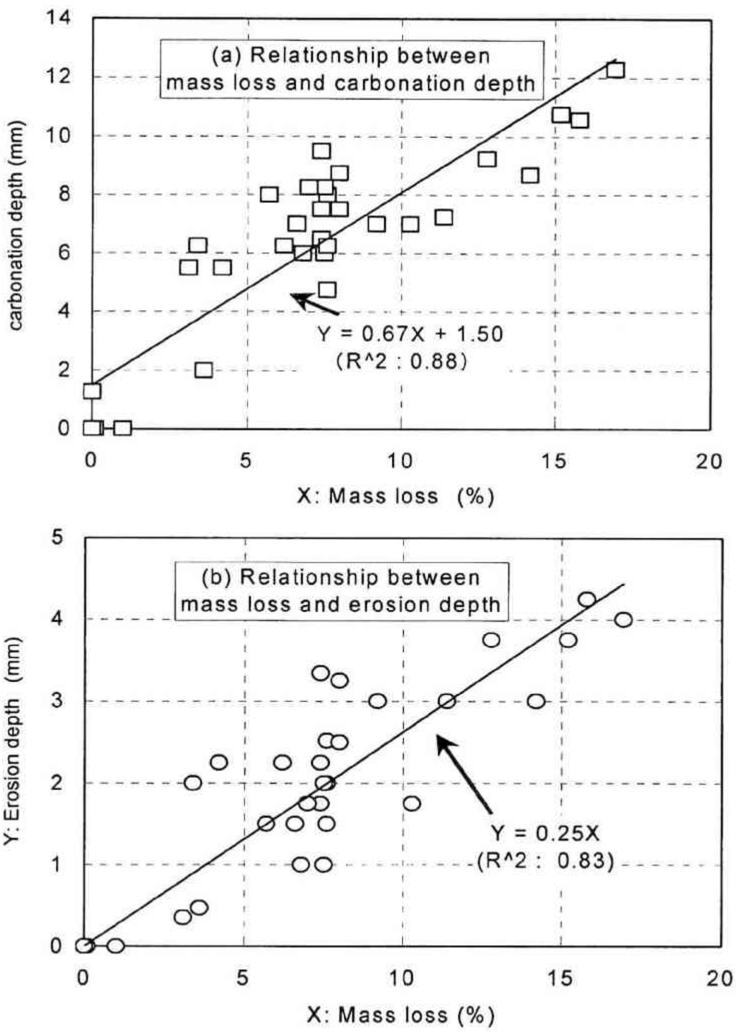

Fig. 7 Relationship between mass loss, carbonation depth and erosion

3.5 Assessment of Concrete Corrosion

The relations between mass loss, carbonation depth, and erosion depth in the systems are shown in **Fig. 7**.

Variations were observed in the linear regression results but the mass loss correlated with the depth of carbonation and erosion.

The main factor causing corrosion from the outside toward the inside of the test specimen is, according to the results of chemical analysis (electron probe microanalysis, X-ray diffraction and fluorescence X-ray: results are omitted in this report), erosive carbon. The erosive carbon present in sewage process water includes free carbonic acid released on reaction with the calcium ions in concrete.

Deterioration of the system under consideration is mainly controlled by the corrosion rate of concrete. However, a decline in the performance of reinforced concrete may occur if corrosion occurs in the concrete cover and the reinforcing rods. Therefore, corrosion may invade more deeply than the index indicates.

Thus, the progress of carbonation and decrease of cover concrete become the most important indices of deterioration.

4. Conclusion

In this processing system, corrosion is considered to have been mainly cause by erosive free carbonic acid. The carbonates decompose cement hydration products of concrete and finally reduce them to ions. The structure is gradually destroyed through the mechanism of ion dissolution.

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