Effects of Coarse Aggregate Content on Sulfuric Acid Deterioration of Concrete

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ABSTRACT

Recently, the deterioration of concrete structures caused by sulfuric acid attacks has been serious. However, a prediction method for concrete deterioration due to sulfuric acid attack has not been established yet. In this study, the effects of the coarse aggregate content on sulfuric acid deterioration of concrete were investigated. In the experiment, the coarse aggregate content and water cement ratio of concrete were varied and concrete specimens were immersed in four different concentrations of sulfuric acid solution (0.006 mol/L, 0.09 mol/L, 1 mol/L, and 2 mol/L). The erosion depth, mass loss and neutralization depth were measured at fixed periods. The results showed that the increase in the volume of coarse aggregate led to the decrease in the rate of sulfuric acid deterioration of concrete. Coarse aggregate was found to contribute to preventing the removal of gypsum produced by the reaction of sulfuric acid with calcium compounds.

Keywords. Coarse Aggregate, Sulfuric acid, erosion depth, mass loss , neutralization depth

1 INTRODUCTIONS

There are various acid solutions that cause chemical deterioration of concrete, and a particular attention has been paid to sulfuric acid. Recently, the deterioration of concrete caused by sulfuric acid attacks in sewage and waste water treatment plants has been reported. In sewage and waste water treatment plants, sulfuric acid is generated by microorganisms, and this causes sulfuric acid deterioration of concrete. However, a prediction formula of sulfuric acid deterioration of concrete is not yet established because the deterioration proceeds in unseen places such as underground sewers. . In the previous studies, the deterioration of sulfuric acid has been reported to be affected by the concentration of sulfuric acid and the water cement ratio. However, most of the experiments were carried out using cement paste and mortar specimens. Even in the case where concrete specimens were used, the effect of coarse aggregate on the deterioration was barely considered. For this reason, it is hard to apply the results of previous studies when predicting the deterioration of existing structures. It is necessary to consider the effect of coarse aggregate on the deterioration in

order to apply the results of previous studies using mortar to existing concrete. In this study, concrete was immersed in various concentrations of sulfuric acid solutions. Therefore, the purpose of this study is to investigate the effect of coarse aggregate on the deterioration of concrete caused by sulfuric acid.

2 EXPERIMENTAL OVERVIEW

2.1 Materials. Normal Portland cement (Density: 3.16 g/cm^3; Specific surface area: 3360 cm^2/g) was used as binder. Crushed sand(surface-dry density: 2.60 g/cm^3; absorption 1.06 %) was used as fine aggregate, while Crushed stone(surface-dry density: 2.62 g/cm^3; absorption 0.69 %$^)$ was used as coarse aggregate. In addition, a thickener (methyl cellulose type) was used to disperse coarse aggregate homogeneously in concrete when the volume ratios of coarse aggregate in concrete are 17 % and 18 %.

2.2 Mix proportion of specimens. Table 1 shows the mix proportion adopted in this study. W/C is 0.55 and 0.40, the volume ratios of the coarse aggregate are 0 %, 18 % (W/C=0.40, 17 %), 37 % (W/C=0.40, 35 %), 50% and the name of the specimens are G0, G18(G17), G37(G35), and G50. In addition, the numbers following the letter "G" indicates the volume ratio of the coarse aggregate. And, it is added the thickener in G17,G18.

2.3 Outline of specimens. Prismatic concrete specimens measuring $100 \times 100 \times 400$ mm in size (W/C=0.55, 0.40) were prepared and demolded after 24 hours , and thereafter were cured in water at 20 degrees for 27 days .At the age of 28 days, the specimens were cut into three equal pieces. The pieceswere then coated with acid resistant epoxy-acrylic, leaving the cut side exposed to the sulfuric acid solution.

2.4. Concentration of sulfuric acid solution. In this study, fourconcentrations of sulfuric acid solution, 0.006 mol/L, 0.09 mol/L, 1 mol/L, and 2 mol/L were used.

2.5 Measurement parameter.

(1)Erosion depth. Figure.1 shows a schematic diagram representing the deterioration depth.The erosion depth here is defined as the difference between the initial length of the specimen and the length measured after erosion, which was measured using a vernier caliper. Before immersing the specimens in sulfuric acid solution, the lengths of the specimens were measured at 4 different points so as to obtain the initial values of erosion depth. Thereafter, the erosion depth was measured as the difference between the averages of the initial length and the measured length after immersion of a fixed period of time. In addition, in the case where the value measured was smaller than the initial value, the difference was considered a positive and vice varsa.
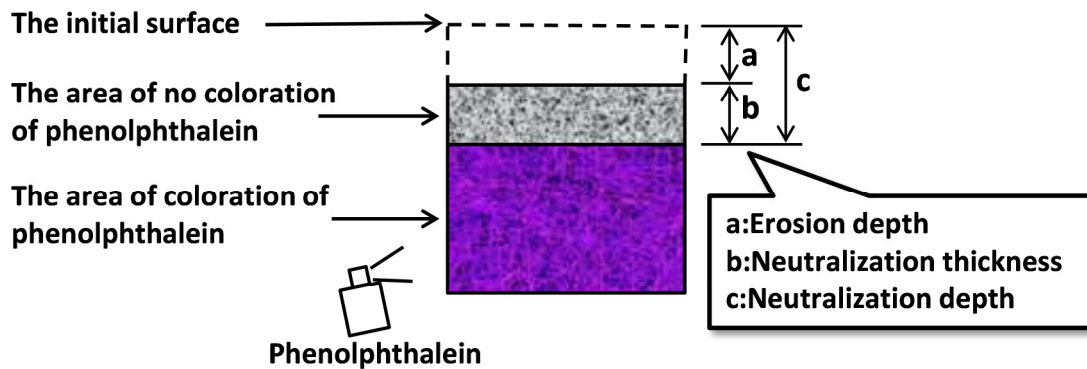
Figure1. Schematic diagram of deterioration depth

(2)Mass loss. Mass loss was measured using a mass meter of a minimum graduation of 0.1 g at fixed durations. In the case where the mass of specimen after immersion was smaller than the initial value before immersion due to deterioration, the mass loss was described as a plus and vice varsa.
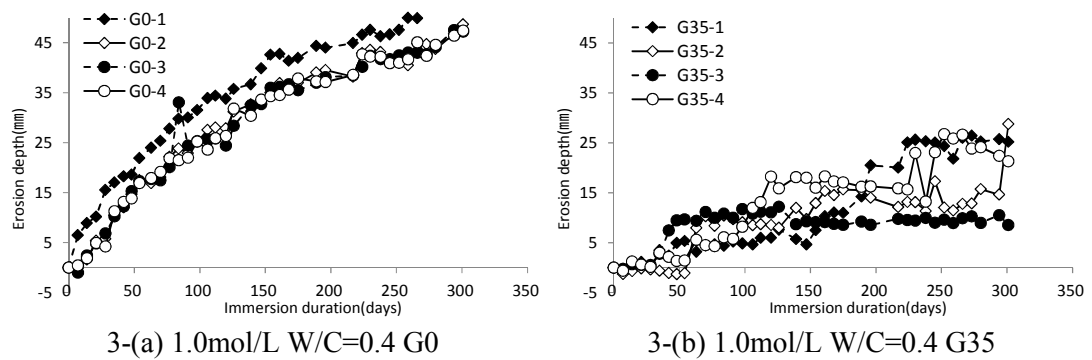
(3)Neutralization depth. The specimens immersed for a fixed period were split into two pieces using a compression testing machine .The split sections were sprayed with phenolphthalein solution, and the length of the discoloured region was measured in the same method was the one applied in the measurement of the erosion depth, and the measured value was defined as Neutralization thickness. The total length of this Neutralization thickness and erosion depth of the same specimen is defined as Neutralization depth

Table1. Mix proportion of concrete specimens.

Names	W/C(%)	Unit Content (kg/m^3)			
		W	C	S	G(5~20 mm)
G0	40	266	664	1146	0
G17		220	549	949	452
G35		174	435	751	905
G50		132	332	573	1310
G0	55	274	498	1253	0
G18		224	407	1074	479
G37		174	316	795	958
G50		137	249	626	1310

2-(a) 1.0mol/L W/C=0.55

2-(b) 1.0mol/L W/C=0.4

2-(c) 2.0mol/L W/C=0.55

2-(d) 2.0mol/L W/C=0.4
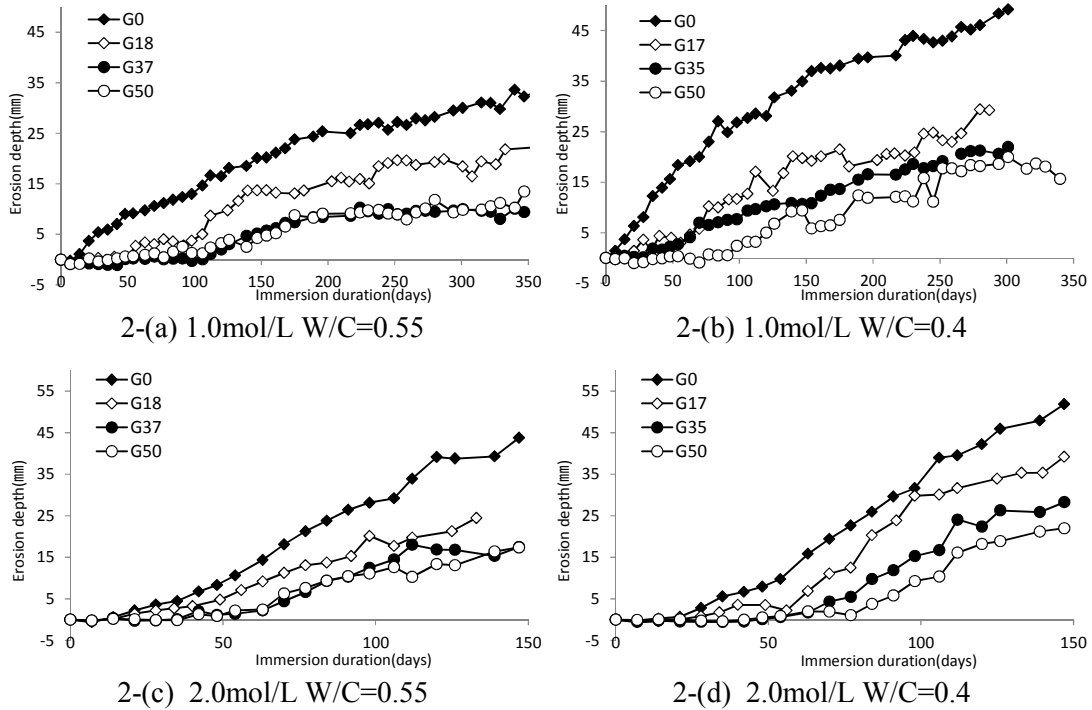
Figure 2. Relationship between Immersion duration and Erosion depth

3-(a) 1.0mol/L W/C=0.4 G0

3-(b) 1.0mol/L W/C=0.4 G35

**Figure 3. Erosion depth of at each set position of the specimen**

3 EXPERIMENTAL RESULTS .

3.1 Erosion depth. Figure 2 indicates the relationship between immersion duration and erosion depth. (a), (b), (c), and (d) in Figure 2 indicate the averages of the erosion depth for three same specimens , (a), (b) in figure 3 indicate the erosion depth at each set position of specimen of G0 and G35 (1.0 mol/L of sulfuric acid solution, W/C=0.4). Peeling from the surface of G0 specimen is observed to begin comparatively early. The beginning of peeling was defined as the time when a positive value of erosion depth was obtained. However, the other specimens begin to peel after a fixed term though the term differed with each specimen. The Erosion depth of G0 with no coarse aggregate was observed to increased linearly with increase in immersion duration. However, in the case where course aggregate was used, the erosion depth was not linear. The deterioration of concrete due to sulfuric acid occurs when

4-(a) 1.0mol/L W/C=0.55

4-(b) 1.0mol/L W/C=0.4

4-(c) 2.0mol/L W/C=0.55

4-(d) 2.0mol/L W/C=0.4
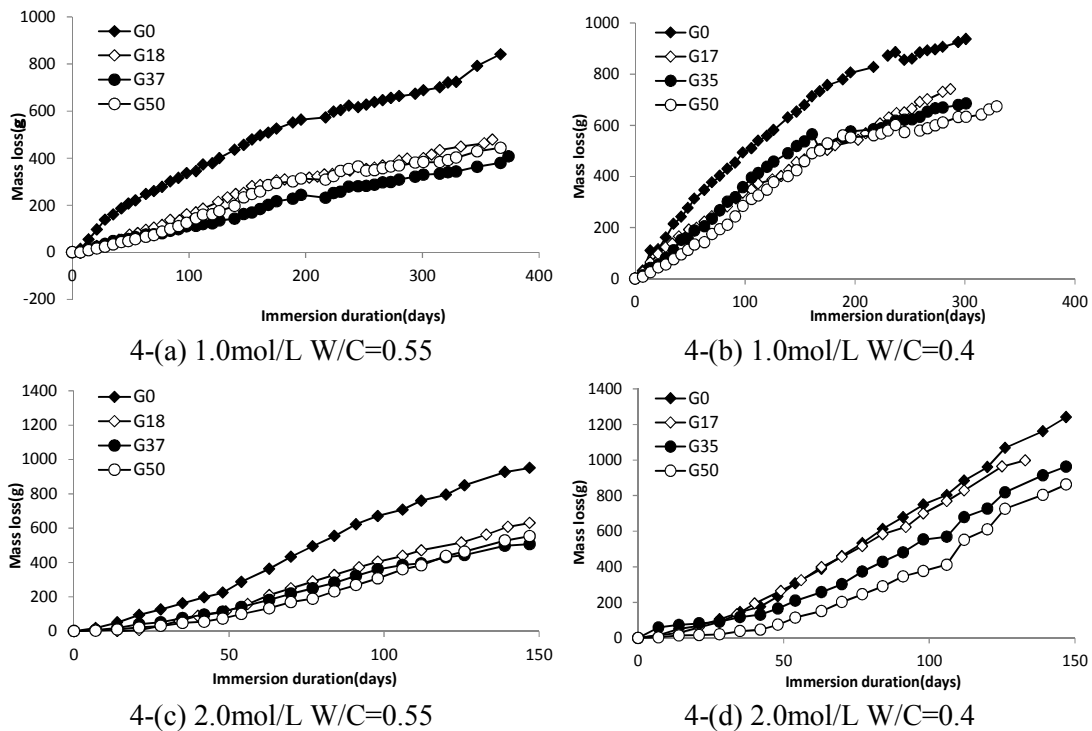
Figure4. Relationship between Immersion duration and Mass loss

sulfate ions penetrate into concrete and react with calcium ions. The end product of the reaction is gypsum, which expands, and once it exceeds the pore sizes, the surface of the specimen peels. The peeled concrete exposes the unaffected concrete which allows for continued penetration of the sulfate ions. At this time, it is considered that coarse aggregate contains the removal of gypsum, since the beginning of peeling was different between specimen of G0 and the other specimens because coarse aggregate prevent the erosion for a fixed period. Comparing between W/C and concentration of sulfuric acid solution, it was observed that the erosion depth was larger for the specimens with lower W/C and higher concentrations of sulfuric acid solutions**.** This can be explained in two reasons. First, there are a large number of sulfate ions in high concentration of sulfuric acid solution, and the sulphate ion reacted with calcium ions.Secondly,, there is more amount of cement per unit in low ratio of W/C, and calcium ion react with sulphate ions. Moreover, the pore size of concrete is narrow in low ratio of W/C, which blocks the penetration of sulphate ion into concrete. The increase in calcium ions prevents deterioration, on the other hand, the decrease in pore volume of concrete accelerates the deterioration. Previous studies, (Hisada, 2008), have reported that the effect of the latter excels more than that of the former in the case of concentrations, 1.0 mol/L and 2.0 mol/L of sulfuric acid solution. In this study, a similar tendency as the one observed in the previous study was obtained. In addition, the erosion depth of G0 is the largest of all the specimens in 1.0 mol/L and 2.0 mol/L of sulfuric acid solution, and it was also observed that the erosion depth becomes larger as the volume ratio of coarse aggregates decreases. From this result, it is estimated that increase in the volume ratio of coarse aggregate prevents the erosion depth, and conequently preventing deterioration. In addition, comparing the erosion depths of specimens with different W/C, as well as the concentration of sulfuric acid solution, the period of the beginning of peeling and distinction of each specimen are different in each situation. From this, it is considered that the effect of coarse aggregate in controlling deterioration is different depending on the W/C and sulfuric acid solution concentration.

5-(a) 1.0mol/L   5-(b) 2.0mol/L
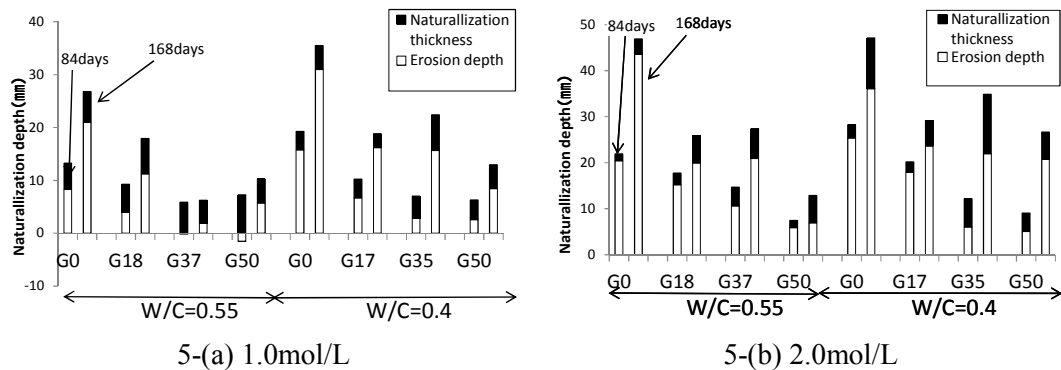
Figure5. Neutralization depth

3.2 Mass Loss. Figure 4 indicates the relationship between the immersion duration and mass loss. From this figure, similarly to the erosion depth, the mass loss of G0 is the biggest in all cases. All the figures indicate a tendency that the lower the coarse aggregate volume ratio, the bigger the mass loss. The reason for this is that the specimens with low volume ratio of coarse aggregate have large areas of mortar per section exposed to sulphuric acid. And it is estimated that the coarse aggregate has the effect of preventing the peeling of gypsum. In the case of mass loss, it was confirmed that this effect is different with change in W/C and concentration of sulfuric solution.

3.3 Neutralization. Figure 5 indicates the results of Neutralization depths. In Figure5, the left bar indicates the result at 84 days, and the right one the result at 168 days. The neutralization depth of G0 is the biggest, and furthermore, the neutralization depth was observed to become smaller with increase in course aggregate. t. This shows that the coarse aggregate prevented the increase in neutralization depth. The neutralization thickness equals the amount of gypsum in this bar graph. The neutralization thicknesses of the other specimens are bigger than that of G0 specimen, which indicates that the specimen with more coarse aggregate controls the peeling of gypsum.

4 CONCLUSIONS

• The increase in the volume of coarse aggregate controlled the progress of sulfuric acid deterioration of concrete

• The effect of course aggregate in mitigating peeling of concrete differed with different W/C and sulfuric acid concentrations.

5 REFERENCE

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