INFLUENCE OF REBAR CORROSION BY CHLORIDE AND CARBONATION OF MORTAR SURFACE STRAIN

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ABSTRACT: In this study, we performed the accelerating corrosion test using wet and dry conditions by simulating the rebar corrosion due to chloride and carbonation. The purpose of the accelerating corrosion test is to get the amount of corrosion area and weight loss which the cracking occur on mortar surface by chloride and carbonation. As a result, the amount of corrosion area and weight loss of rebar corrosion due to chloride and carbonation is a case of the same degree, the surface strain of mortar was different in the case of chloride and carbonation. The results of the experiment showed that the difference of rebar corrosion due to chloride and carbonation affect the cracking behavior of mortar surface.

1   INTRODUCTION

Chloride and carbonation induced deterioration is serious damage in the RC structure. Carbon dioxide which penetrated into concrete from the atmosphere reacts with the cement hydration. As a result, the passivation coating on the rebar surface is lost, because the pH value in concrete is lowered due to carbonation reaction. And, the corrosion of rebar progresses with the supply of water and oxygen. Additionally, in chloride, the corrosion of rebar is accelerated with chloride ions which are present in the concrete. The cracking and peeling in cover concrete occurs due to the expansion of corrosion products on rebar. Furthermore, the performance of the RC structure is reduced, because the rebar cross sectional area is decreased. The corrosion rate of rebar become more rapid due to increased supply of oxygen and water when the crack has occurred. Therefore it is important to understand that the amount of corrosion area and weight loss at occurring cracks on concrete surface, in order to make the prediction of deterioration progress by chloride and carbonation on RC structures.

Researchers have been studying relationship between corrosion degree of rebar and case of cracking in concrete (e.g. Nakagawa and Matsushita (2008)). They have been studied such as by the accelerating corrosion test using wet and dry conditions by simulating chloride, and the electrolytic corrosion test. However, places to corrosion of rebar in electrolytic corrosion experiment would significantly incline to one side when there is a crack. Also, it has been proposed that the corrosion products in the electrolytic corrosion test is different from the corrosion products in a real environment. In addition, the progress of corrosion by carbonation is remarkably slower than case of chloride (e.g. Takaya and Miyagawa (2013)). Although a large number of researchers have been carried out into the relationship between corrosion

degree of rebar and case of cracking in concrete by chloride, little is known about the progress of corrosion by carbonation.

In this study, we performed the accelerating corrosion test using wet and dry conditions by simulating the rebar corrosion due to chloride and carbonation. The purpose of the accelerating corrosion test is to get the amount of corrosion area and weight loss which the cracking occur on mortar surface by chloride and carbonation.

2   EXPERIMENTAL

2.1   Mix proportion and specimens

Table 1 shows the mix proportion of mortar. In this study 2 different specimens were prepared with water cement ratios (W/C) of 65 % and 150 %. And, sand cement ratio (S/C) was 3.0 and 5.0. The specimen of 150% of W/C was used with high-performance thickening agent in order to prevent the material separation.

Table 1. Mix proportion of mortar.

Water-cement ratio (%)	Sand-cement ratio	Unit mass (kg/m^3)			
		W	C	S	Vis
65	3.0	309	475	1427	-
150	5.0	404	207	1348	W×3.0%

The specimen details of this study are shown in Figure 1. There were 2 types of this experiment, one test was carried out on 60x60x80 mm rectangular parallelepiped specimens and specimens with the strain gauge attached. The strain gauges that were attached to the specimen was waterproof type strain gauge. Rebar was placed in such a way that 5, 7.5, 10mm from mortar surface. Rebar used in the specimen was round rebar with length of 90mm (L=90mm) and diameter of 10mm (φ=10mm). Rebar has been coarse polishing in advance by sandpaper of grain size No. 80. The rebar to remove oil of rebar surface by immersing in acetone. It should be noted that the rebar's range is 15mm from both ends in order to corrode 60mm in length direction of rebar which was coated in epoxy resin. After curing, the side and bottom of specimens were coated by epoxy resin, except top surface for the accelerating corrosion test using wet and dry conditions.
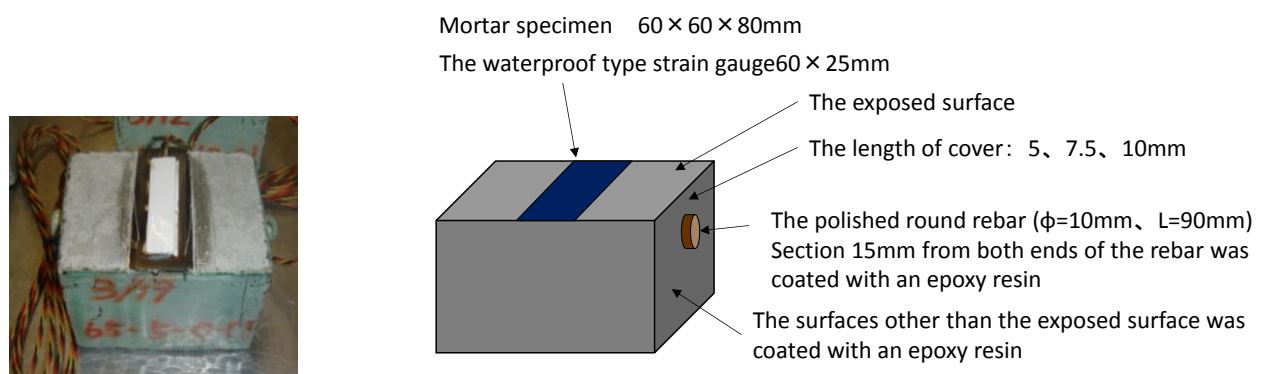

Mortar specimen　60×60×80mm
The waterproof type strain gauge60×25mm
The exposed surface
The length of cover：5、7.5、10mm
The polished round rebar (φ=10mm、L=90mm) Section 15mm from both ends of the rebar was coated with an epoxy resin
The surfaces other than the exposed surface was coated with an epoxy resin

Figure 1. Overview of mortar specimen.

2.2   Curing Conditions

Figure 2 shows the experimental cases of mortar specimens and the curing conditions. The specimens were classified with the case simulating chloride and carbonation. The specimen was cured at each of the conditions after mortar was placed. After curing, the specimens simulating chloride were immersed in 10 % NaCl solution for a period in which the pre-chloride ion penetration depth becomes approximately 5mm, 10mm, and 15mm. The pre-chloride ion penetration depth in each specimen was measured by the method of spraying silver nitrate. In case of neutral test body is exposed to accelerated carbonation of 5% carbon dioxide concentration, temperature of 20℃, and humidity 60% RH. The specimens were exposed to period in which the carbonation depth was approximately 5mm, 7.5mm, and 10mm.
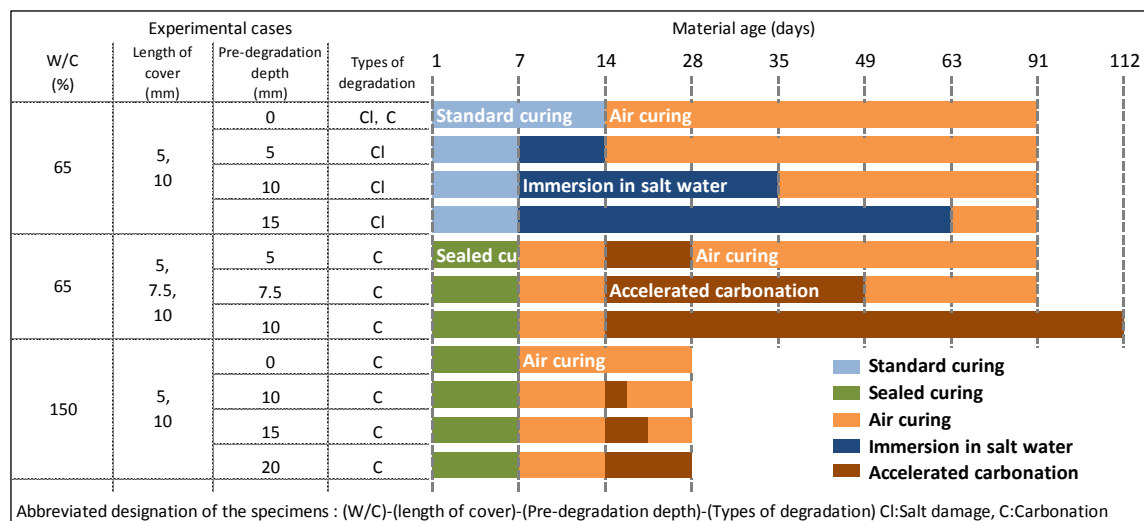

Figure 2. The experimental cases of mortar specimens and the curing conditions.

2.3   The accelerating corrosion test using wet and dry conditions

In the accelerating corrosion test using wet and dry conditions, the specimens simulating chloride were immersed in 40℃, 10 % NaCl solution for 3 days. The immersed specimens were removed from 10 % NaCl solution and then were dried at 20℃, humidity 60% RH for 4 days. This wet and dry conditions cycle was repeated for each period. The specimens simulating carbonation were immersed in 40℃, tap water for 3 days. Then dried for 4 days. It collected rebar in any of corrosion promotion period by splitting the specimen. And to calculate the ratio of corrosion area and the ratio of weight loss.

Corroded rebar was replicating the range corroding to the transparent sheet. The measured range that were used to calculate the ratio of corrosion area is by using image processing. The ratio of corrosion area calculated the corroding area divided by the rebar surface area. The corroded rebar was immersed in 60℃, 10 % diammonium hydrogen citrate solution for 12 hours in order to remove the corrosion products and mortar. And corroded rebar removed the corrosion products and mortar, were weighted. The measured weights were used to calculate the ratio of weight loss. The ratio of weight loss is the ratio of the difference between the rebar weight after corrosion to the rebar weight before the accelerating corrosion test. In addition, the mortar specimens to continuously measure the surface strain of mortar specimens by strain gauge.

3 RESULTS AND DISCUSSION

3.1 The amount of corrosion area and weight loss

Figure 3 shows the ratio of corrosion area and the ratio of weight loss. In specimen simulating chloride, the ratio of corrosion area and the ratio of weight loss varied depending on except specimens which pre-chloride ions were impregnated to 15mm (65-10-15-Cl) was detected at the accelerating corrosion period of 65 days. It is highly probable that 65-10-15-Cl is highest chloride ion resistance mortar, due to hydration of cement to proceed in order for long period curing.

In specimen simulating carbonation at 10mm of length of cover (65-10-10-C), the ratio of corrosion area and the ratio of weight loss were lower than those of 5mm, 7.5mm of length of cover when compared with the same specimen at 65% of W/C. The ratio of corrosion area of 65-10-10-C is 35.8%, and the ratio of weight loss is 0.22%. In specimen simulating carbonation at 5mm of length of cover 150% of W/C, the ratio of corrosion area of specimen that 20 mm of Carbonation depth (150-5-20-C) is 100%. And, the ratio of weight loss is 1.34%. Corrosion degree of specimen at 20 mm of carbonation depth (150-5-20-C) is higher than specimens that 10mm, 15mm of carbonation depth. In addition, the specimens that were not subject to carbonation did not corrode at the accelerating corrosion period of 171 days.
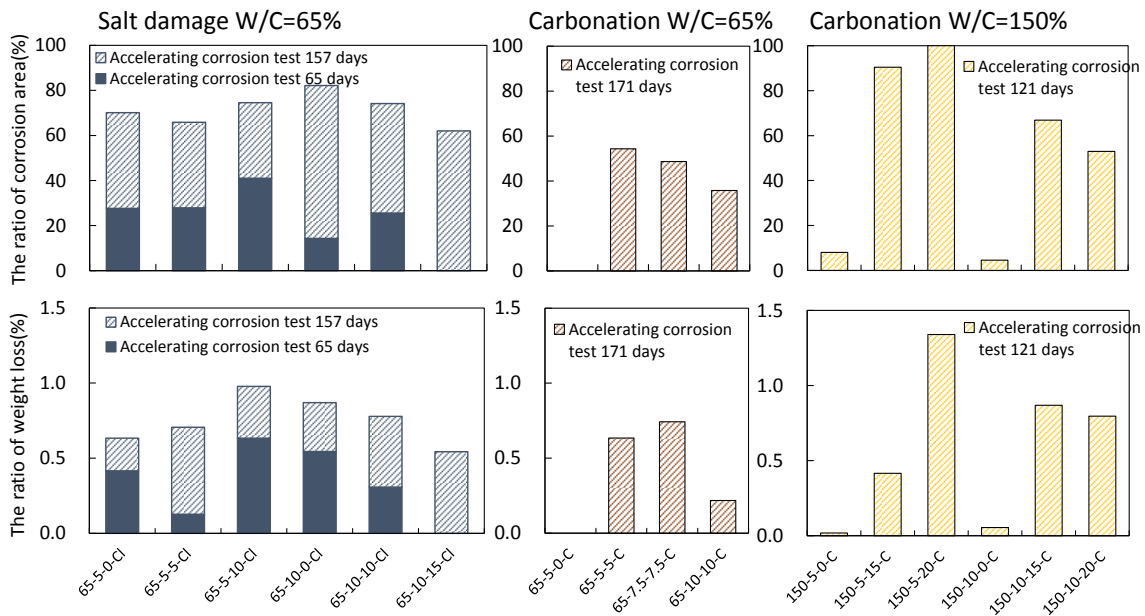

Figure 3. The ratio of corrosion area and the ratio of weight loss.

Next, Figure 4 shows the relationship between the ratio of corrosion area and the weight loss. In addition, in the figure also shows the relationship between the amounts of corrosion weight loss against corrosion area (the weight loss / the corrosion area). The relationship between the ratio of corrosion area and the weight loss were found with a different trend in each degradation mechanism of chloride and carbonation. In specimen simulating carbonation, the relationship between the amount of corrosion weight loss against corrosion area becomes 0.01～0.05g/cm^2. On the other hand, specimen simulating chloride is also larger than the specimen simulating carbonation in the weight loss / the corrosion area. Specimen simulating chloride is also larger than the specimen simulating carbonation in the relationship between the amounts of corrosion weight loss against corrosion area. We suggest that the weight loss / the corrosion area is increased if places to corrosion of rebar would significantly incline to one side, In case of same amounts of corrosion.
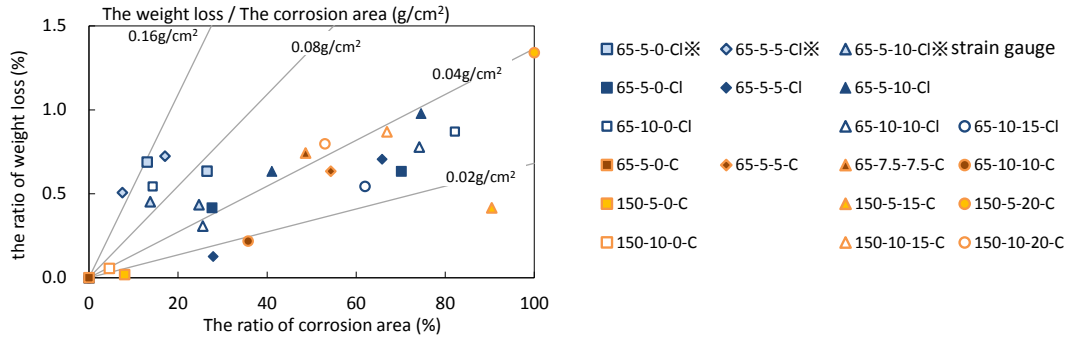
Figure 4. The relationship between the ratio of corrosion area and the weight loss.

3.2 The surface strain of mortar specimen

Figure 5 shows the result of continuously measurement of the surface strain of mortar specimens. The surface strain of mortar showed the expansion behavior of about $200 \sim 400 \times 10^{-6}$ immediately after the start of the accelerating corrosion test in all of the specimens. Since all of the specimens are dry which were expanded by absorbing water. The surface strain of mortar showed contraction and expansion behavior of about $100 \sim 150 \times 10^{-6}$ in one cycle period of the influence of wet and dry conditions. In specimen simulating chloride which pre-chloride ions were impregnated to 0mm, 5mm (65-5-0-Cl, 65-5-5-Cl), the maximum value of the surface strain in one cycle showed a constant value until about 50 days. After that, the maximum value of the surface strain in one cycle showed expansion behavior from about 50 days later. It is assumed that the variation of the surface strain is due to the rebar corrosion.
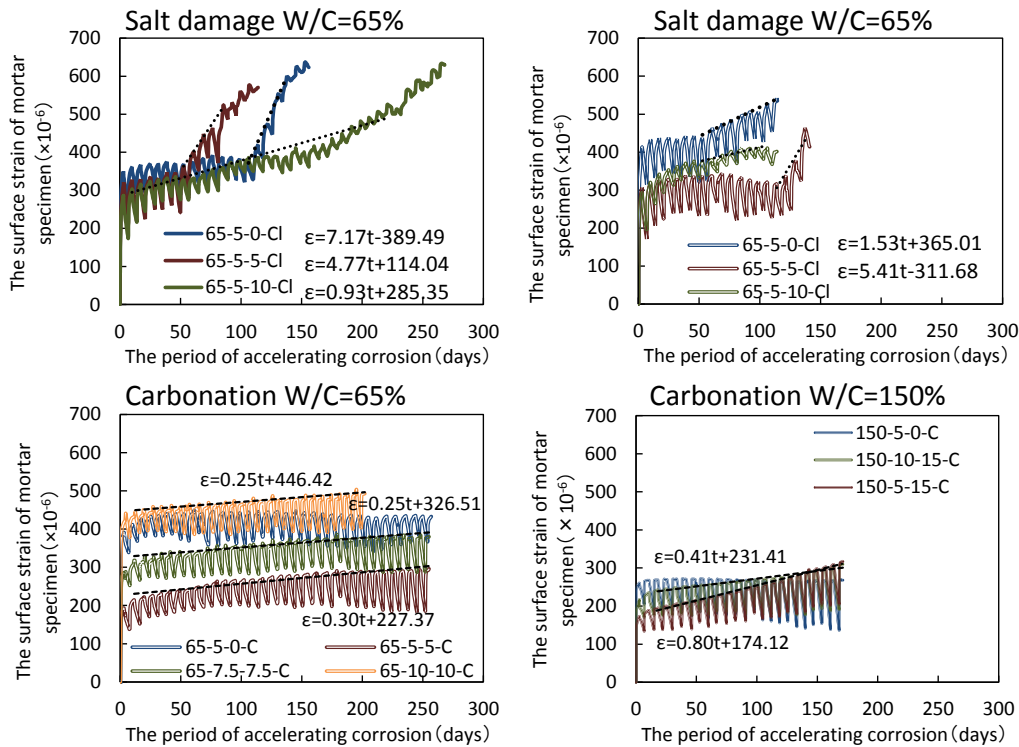

Figure 5. The surface strain of mortar specimen.

The surface strain of 65-5-5-Cl showed a rapidly increasing trend due to rebar corrosion. On the other hand, the specimens of 65-5-10-Cl which is a clear inflection point but was not confirmed. It showed a behavior that increases gradually. Next, approximating the maximum value of the surface strain in one cycle, we can calculate the velocity of increase $(d\varepsilon/dt)$ in the surface strain. The velocity of increase $(d\varepsilon/dt)$ in specimen simulating carbonation became large as the length of cover is smaller. With the

same results in Figure 3, dε/dt became larger as the corrosive conditions when the length of cover is smaller.

Figure 6 shows the relationship between the weight loss /the corrosion area and dε/dt. In specimen simulating chloride, the value of the weight loss /the corrosion area increases and the value of dε/dt increases as in the 65-5-10-Cl. The corrosion form which Corrosion weight loss / corrosion area is 0.1g / cm^2 shows rapid change to the surface strain of mortar. In view of the relationship between the weight loss /the corrosion area and dε/dt, the locally significantly corrosion form showed behavior of surface strain different from the uniformly corrosion form.

As a result, the amount of corrosion area and weight loss of rebar corrosion due to chloride and carbonation is a case of the same degree, the surface strain of mortar was different in the case of chloride and carbonation. The results of the experiment show that the difference of rebar corrosion due to chloride and carbonation affect the cracking behavior of mortar surface.
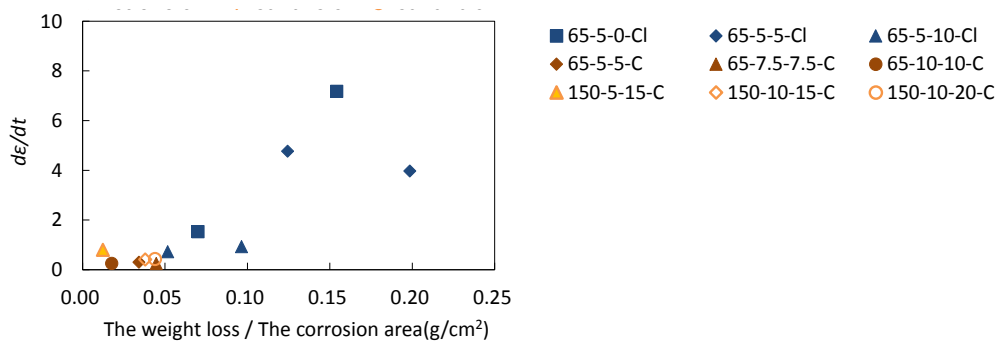

Figure 6. The relationship between the weight loss /the corrosion area and dε/dt.

4   CONCLUSION

The results obtained from the experiments are summarized as follows:

(1) It is possible to represent the difference of corrosion form by using the weight loss /the corrosion area, corrosion rate results.

(2) In the accelerating corrosion test using wet and dry conditions, the specimen simulating chloride is also larger than the specimen simulating carbonation in relationship between the amounts of corrosion weight loss against corrosion area.

(3) The locally significantly corrosion form showed behavior of surface strain different from the uniformly corrosion form.

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