

A study on corrosion properties of rebar in fly ash concrete

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ABSTRACT

The purpose of this study is to investigate the effect of mix of fly ash on the corrosion properties of rebar in concrete. The presence or absence of fly ash replacement, cover and concrete curing condition were taken up as an experiment factor, and the half-cell potential, polarization resistance, water permeation depth and chloride ions permeation depth were measured. When the fly ash is mixed as the cement replacement, the anti-corrosion properties of the rebar in concrete subjected to the drying process during the curing become much lower than those of the conventional concrete. On the other hand, the rebar in concrete subjected to the wetting process during the curing has extremely high anti-corrosion properties, although the chloride ion concentration in the vicinity of rebar did not change with the difference in the curing process.

Keywords. Fly ash, Corrosion, Half-cell potential, Permeation of chloride ions

INTRODUCTION

Presently, Japan has to depend on coal for its thermal power generation, and it is a natural course of events that in the future, the disposal of a lot of waste coal ashes produced by power plants running with coal will become an issue. With this present situation as a backdrop, replacement of cement with coal ashes for application as concrete admixture is receiving attention as the most effective waste disposal method. This replacement with coal ashes is one method of coal ash disposal. It has been highlighted in previous studies that the concrete with fly ash has excellent fresh properties and mass transfer resistance. In order to apply fly ash concrete to the RC members, the steel corrosion due to salt attack and neutralization of concrete have to be investigated.

Although the mass transfer resistance in concrete of such substances as chloride ions is enhanced with the mixture of fly ash (Okazaki 2012), anti-corrosion properties of rebar is degraded because of lower basicity. The balance between mass transfer resistance enhancement and anti-corrosion property degradation has to be taken into consideration in mixing fly ashes in concrete. It can be surmised that in fly ash concrete the cover thickness has to be sufficiently deeper than that of the conventional concrete in order to provide sufficient durability in the service life. As described above, the cover concrete is an important factor in studying the influences of fly ash on the anti-corrosion properties of the rebar, and thus it is a focus of investigation in this study. The presence or absence of fly ash

replacement, cover and concrete curing condition were prepared for test specimens, and these specimens were repeatedly subjected to wet and dry tests using salt water. The examinations on the half-cell potential, polarization resistance, water permeation depth and chloride ions diffusion properties were conducted.

Table 1. Concrete mix proportion

Specimen	Unit weight (kg/m ³)						
	Cement	Water	Fly ash	Aggregate		WRA	AEA
				Fine	Coarse		
FA40	305	174	131	667	943	0.26	6.53
FA50	244	174	104	783	904	0.21	3.48
OPC40	435	174	---	684	966	0.02	6.53
OPC50	348	174	---	794	921	0.01	3.48

WRA : Water reducing agent, AEA : Air entraining agent

EXPERIMENTAL OUTLINE

Specimen

Water binder ratios used in this study were 40% and 50%. In the case of use of fly ash, 30% of cement was replaced with fly ash, which was the Type-II fly ash (density : 2.21g/cm³). Here after, the fly ash concrete and the concrete without fly ash are denoted as "FA" and "OPC", respectively, with number of water-binder ratio. The ordinary Portland cement (density : 3.16g/cm³) was used. The AE water reducing agent and the AE agent were used as chemical admixture. The specified mix proportion is listed in Table 1.

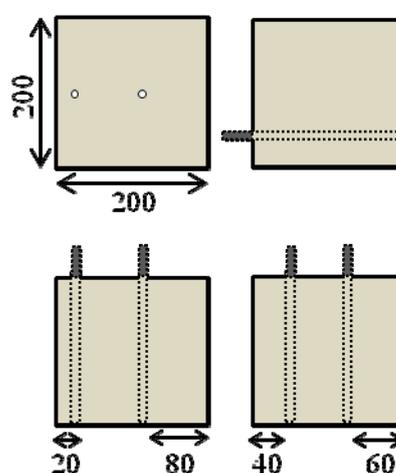


Figure 1. Specimen (mm)

The rectangular prism shaped test specimens of 200×200×200 mm were constructed, each of which has two rebars (diameter : 10mm) with a different cover thickness. One of the specimens has a cover thickness of 20mm and 80mm (denoted as "20-80"), and the other one has that of 40mm and 60mm (as illustrated in Fig. 1). In 24 hours after concrete casting, the specimens were removed from their mold and subjected to atmospheric exposure curing (i.e., they were air-cured) and they were also subjected to wet curing (i.e., they were wet sealed) both at 20°C in laboratory for 28 days. In the wet curing the specimens were covered with cloths soaked with water and sealed with vinyl sheets. After the completion of curing, the faces of the specimens were coated with epoxy resin except for the faces reserved for securing the specified cover thickness so that any substance could not permeate in the concrete.

Corrosion acceleration test and measurement

The specimens were immersed in salt water for 3 days and were then dried for 4 days at 20°C in a laboratory. This wet and dry test cycle of one week was repeated. Concentration of the salt water was set to 10% to further accelerate the corrosion process. The half-cell potential and polarization resistance were measured in every test cycle after the immersion. The reference electrode was the saturated copper sulfate electrode.

After the finish of a prescribed test cycle, specimen was split into two and the permeation depth of salt water was observed. And, by applying drill method, the powder sample at a position of specimen was gathered, and the concentration of chloride ion at the designated position was obtained in accordance with JIS A 1154. Furthermore, after drying process, the air permeability test based on Torrent method (Torrent 1992) was conducted and the intrinsic air permeability coefficient of cover concrete in specimen was calculated.

EXPERIMENTAL RESULTS AND DISCUSSION

Half-cell potential and polarization resistance

Figs. 2 and 3 show the time-dependent change of half-cell potential of the specimen with the concrete cover thickness of 40mm and 60mm, respectively. In the case of water binder ratio 40%, the half-cell potential of specimen using fly ash concrete subjected to atmospheric exposure curing after cast of concrete reaches about -300 mV. However, the half-cell potentials of other specimens are low, about -100 mV or less, except for OPC40Seal. The measurement for OPC40Seal seems that there were some incomplete measurements because the half-cell potential increases rapidly at the very early stage. In the case of water binder

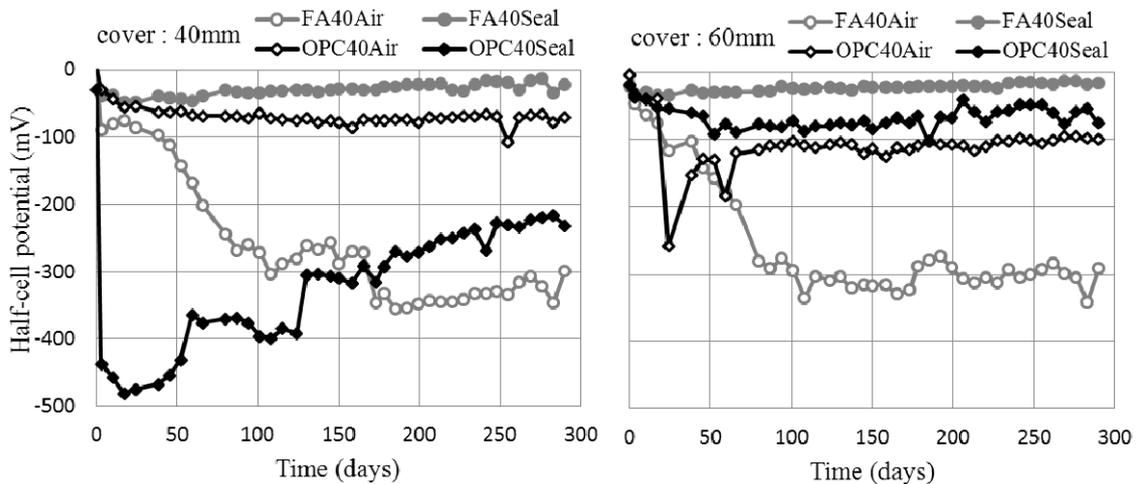


Figure 2. Change in corrosion potential with time (W/B=40%)

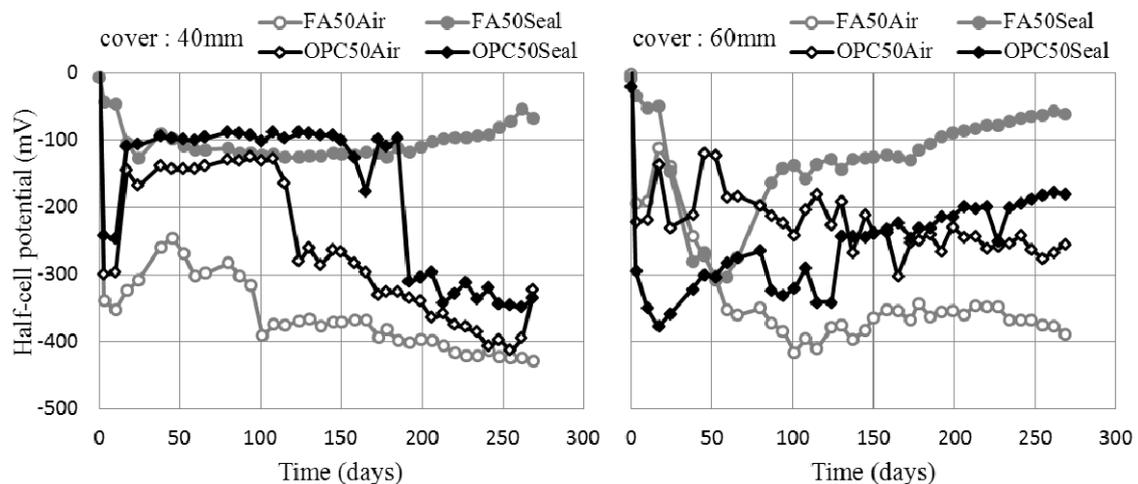


Figure 3. Change in corrosion potential with time (W/B=50%)

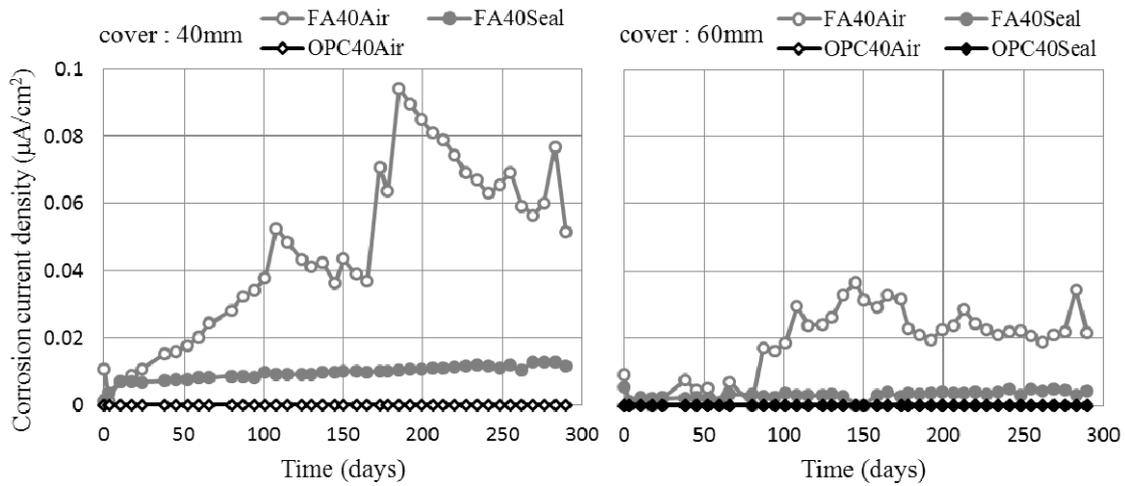


Figure 4. Change in corrosion current density with time (W/B=40%)

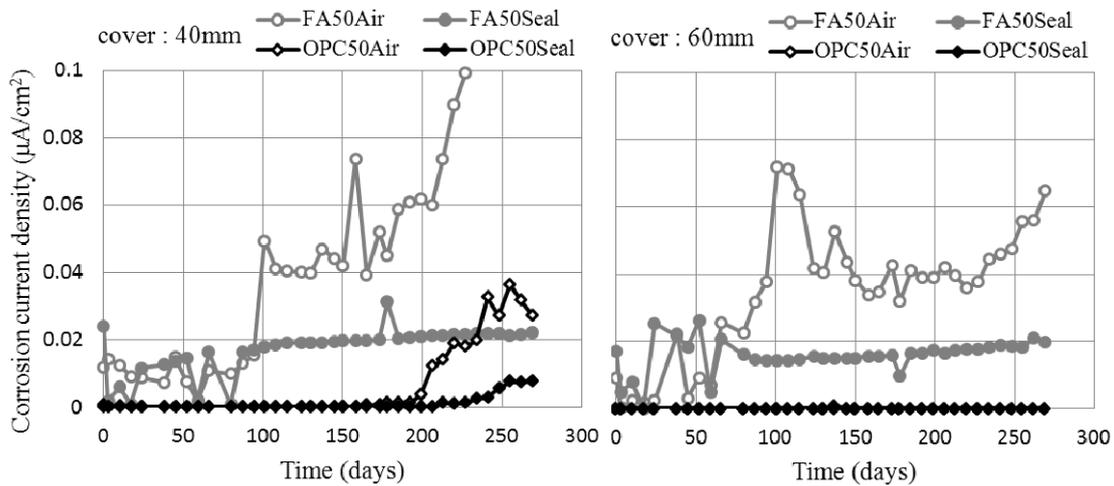


Figure 5. Change in corrosion current density with time (W/B=50%)

ratio 50%, the half-cell potential for FA50Air is reaches about -400 mV and it is lowest value. On the other hand, that for FA50Seal is highest value. This tendency for the half-cell potential is similarly to the case of water binder ratio 40%. Though the results do not show in figure, it is almost the same tendency for the case of cover thickness of 80 mm. But, when the cover thickness is 20mm, the half-cell potential of every specimen becomes lower than -300 mV in about 50 days since the beginning of the test.

The corrosion current density of these specimens is shown in Figure 4 and Figure 5. It is shown that the corrosion current density is significantly high in the fly ash mix concrete when it is insufficiently cured, like the half-cell potential. However, the corrosion current density of all specimens was $0.2 \mu\text{A}/\text{cm}^2$ or less except for the concrete cover thickness of 20 mm. This value ($0.2 \mu\text{A}/\text{cm}^2$) is the basis of the judgment criterion of the CEB (CEB 1997). When the corrosion rate is less than this value, it is evaluated as no corrosion or an extremely slow corrosion rate. The corrosion current density of OPC does not show significant change in its corrosion current density regardless of the differences in the curing process. Judging from both results for the half-cell potential and the corrosion current density,

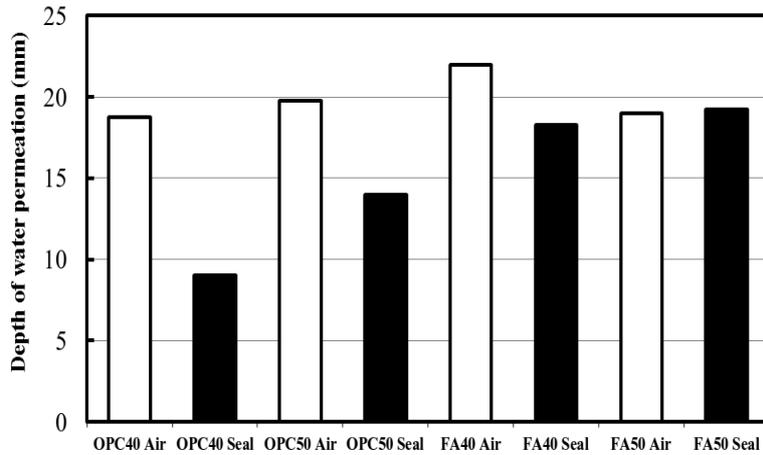


Figure 6. Water permeation depth

whereas the possibility that rebar in fly ash concrete corrodes is high when it is air-cured, it tends to keep the corrosion-free healthy conditions when it is wet seal-cured.

Permeation properties of chloride ions, water and air

The average permeation depth of water infiltrating from two coated faces of the specimen is shown in Fig. 6 for every specimen. It is indicated that, in every specimen, the average water permeation depth of the wet seal cured specimen is shallower than that of the air cured specimen. This is because the pores are more closely packed owing to the wet seal curing process. Also note that the water permeation depth of the fly ash concrete is deeper than that of the concrete without fly ash. However, in general, the pores in the fly ash concrete are packed more closely than those in the concrete without fly ash due to the pozzolanic reaction and the amount of water permeating in the concrete is suppressed by the tightness of pore structure. This increase water permeation depth in the fly ash concrete may be brought about by increased wettability of pore wall surface. The surface wettability is increased by changes in pore surface chemical composition.

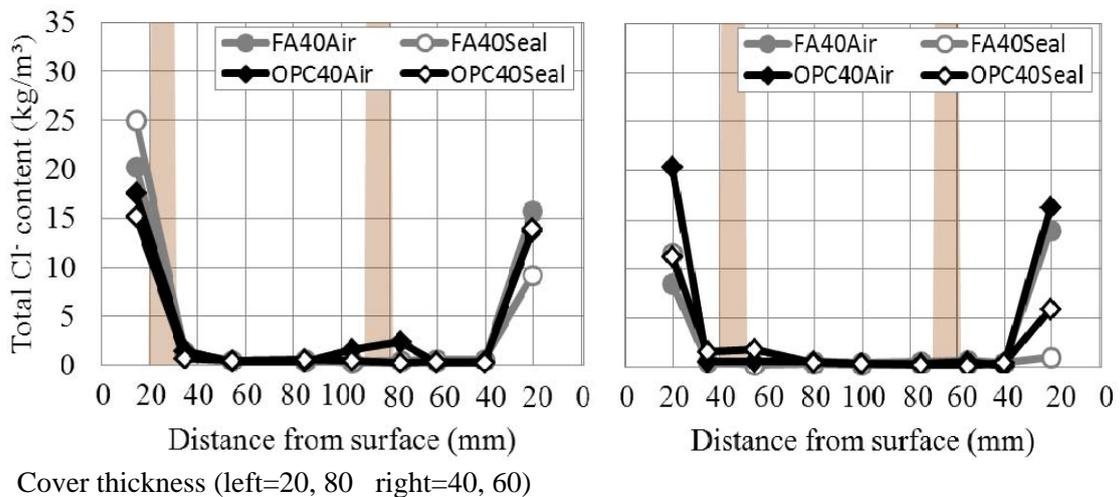


Figure 7. Distribution of chloride content (W/B=40%)

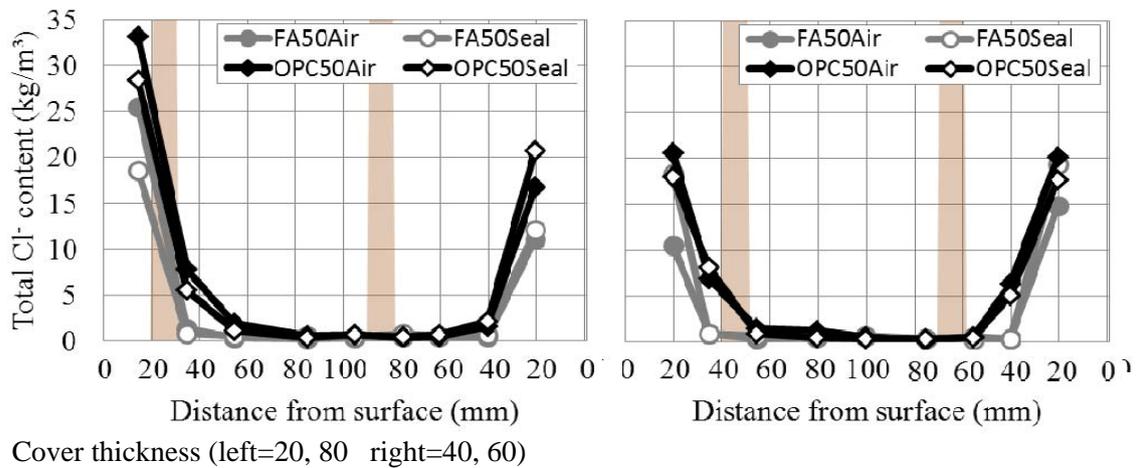


Figure 8. Distribution of chloride content (W/B=50%)

Figs. 7 and 8 show the distribution of chloride ion concentration in each specimen. The gray lines show the position of rebar. When water binder ratio is 40%, chloride ions diffuse into the concrete as deep as 30 to 40mm from the surfaces from which salt water permeates, and the diffusion properties are almost the same regardless of the curing process and whether the fly ashes are mixed or not. On the other hand, when water binder ratio is 50%, the diffusion depth is about 50mm in the concrete without fly ash, and it is about 30mm in the fly ash concrete, indicating that the diffusion depth can be suppressed by about 20mm when the fly ashes are mixed. It is considered that the high mass transfer resistance in the fly ash concrete contributes to this suppression of the diffusion depth.

In Fig. 9, the apparent diffusion coefficient of chloride ions is shown for each specimen. The apparent diffusion coefficient is obtained by curve-fitting the solutions of the diffusion equation against the measurements. The diffusion equation is expressed with an error function whose parameters include the surface chloride ion concentration C_0 and apparent diffusion coefficient D . As for the case of OPC, the apparent diffusion coefficient of the

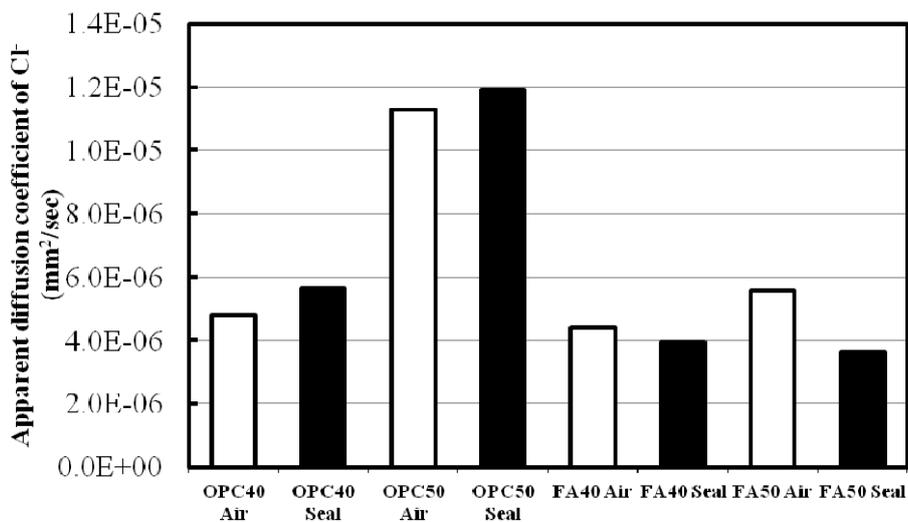


Figure 9. Apparent diffusion coefficient

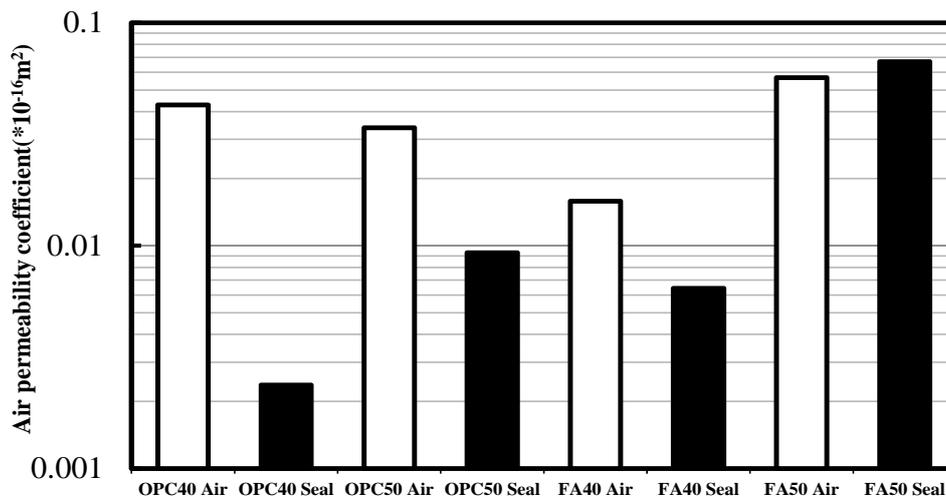


Figure 10. Air permeability coefficient

specimen with water binder ratio of 50% is larger than that of the specimen with water binder ratio of 40%. However, with the case of FA, the apparent diffusion coefficient shows almost the same value, regardless of the water binder ratio and curing. It is understood that the mixing of fly ashes brings about excellent salt proofness.

Fig.10 shows the air permeability coefficient for each specimen. The air permeability coefficient of each specimen was measured with the air permeability testing based on the Torrent method. The air permeability was measured on the not-coated faces of each specimen, and the average of four (two faces on one specimen and two types of the specimen) measurements is shown in this figure. Note that the abnormal measurements were excluded from the averaging operation. It is shown that in each specimen the air permeability coefficient is decreased when the specimen is cured with the wet seal curing process except for FA50. This figure also indicates that the coefficient is almost the same regardless of whether the fly ashes are mixed when the specimen is air-cured. On the other hand, the air permeability coefficient increases with the increase of water binder ratio when the specimen is wet seal cured. In other words, it is considered that the pores are more closely packed due to hydration of cement and pozzolanic reaction of fly ash cured with the wet seal curing process, and that the degree of tightness of pores structure depends on the water-binder ratio.

Discussion

Measurements of the half-cell potential and corrosion current density indicate that if the fly ash concrete is cured insufficiently the concrete will become corroded much earlier than when the corrosion is observed in the concrete without fly ash. On the other hand, the specimen subjected to the wet seal curing process hardly shows the lowered half-cell potential, and its anti-corrosion properties are enhanced far better than the anti-corrosion properties in the concrete without fly ash. In the rest of this paper, this mechanism of corrosion is discussed.

Firstly we focus our attention on the water permeation in the concrete and chloride ion diffusion. As shown in Fig.6, the water permeation depth tends to increase by the mixture of fly ash, but as shown in Figs.7 and 8 the chloride ion diffusion tends to be more suppressed

than the diffusion found in the concrete without fly ash. This trend is found to be more prominent when the water-binder ratio is high. It is noticeable that the fly ash concrete with the same water-binder ratio hardly changes its chloride ion diffusion properties regardless of the curing process. Furthermore, when we focus our attention on the air permeability coefficient thought to be relating to the permeability of oxygen required corroding the rebar, it is found that the air permeability coefficient is decreased in the wet seal-cured specimen except for FA50. It also can be said, based on the above observations and findings, it cannot explain the cause that lower anti-corrosion properties of the fly ash concrete subjected to the drying process during the curing from the viewpoint of differences in chloride ion concentration in the vicinity of rebar and differences in gas permeability such as oxygen or others.

For the fly ash concrete, $[Cl^-]/[OH^-]$ value in the vicinity of the rebar becomes higher as alkaline substances are consumed in the pozzolanic reaction, and thus anti-corrosion properties of rebar are lowered. It is regarded that the half-cell potential was lowered in the early stage when the concrete was subjected to the drying process during the curing. However, due to the consumption of alkaline substances by the pozzolanic reaction, it can't be explained the fact that the fly ash concrete subjected to the wet seal curing process has much better anti-corrosion properties of the rebar than the concrete without fly ash. The reason why the anti-corrosion properties are enhanced when the fly ash concrete is cured in good conditions may be that the corrosion factor such as oxygen cannot reach the rebar due to the modification of vicinity of rebar. It is necessary for this fact to investigate more.

CONCLUSIONS

The following are concluded in this study.

When the fly ash is mixed as the cement replacement, the anti-corrosion properties of the concrete subjected to the drying process during the curing become much lower than those of the concrete without fly ash. On the other hand, the fly ash concrete subjected to the wetting process during the curing has extremely high anti-corrosion properties.

The reason why the anti-corrosion properties of the fly ash concrete showed large differences depending on how the concrete was cured can't be explained by the viewpoint of chloride ion concentration in the vicinity of rebar and the permeability performance of cover concrete.

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