REBAR CORROSION OF FLY-ASH MIXED CONCRETE ACCORDING TO THE PLACING ENVIRONMENT

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ABSTRACTS: In this study, RC mock-up wall specimens with fly ash were manufactured in normal and hot environments, and the effect of the quality of concrete surfaces on carbonation and corrosion of rebars was compared and reviewed. As a result, the density of the surface of the wall specimen placed in a hot environment is lower than that of the normal environment, so the rate of carbonation is accelerated. That tendency accelerates as the replacement rate of fly ash increases, but the depth of carbonation in the normal environment is similar to that of NPC up to 20% of the replacement rate of fly ash, and the half-cell potential value and polarization resistance value of rebars were the same or higher. However, if the addition rate of fly ash is excessive, the depth of carbonation of concrete became very large regardless of the construction environment, so the corrosion rate of rebar also increased rapidly.

KEYWORDS: Hot and normal environment, fly ash mixed concrete, surface water absorption test, carbonation rate, half-cell potential, polarization resistance.

1. INTRODUCTION

The greatest threat to RC durability is corrosion of reinforcing steel, with associated cracking, staining, and spalling of the concrete cover [1]. The quality of covered concrete plays a pivotal role in determining the durability of reinforced concrete structures, as it acts as a protective barrier against external degradation factors that can corrode rebars. As one of the ways to improve the quality of covered concrete, adding fly ash generated from thermal power plants to concrete can produce economical and high-quality concrete [2,3,4]. However, since fly ash has the possibility to accelerate the carbonation of concrete [5,6], one of the factors that corrodes rebars, it can be said that it is still not utilized as a building structural material.

In this study, in order to review the usability of fly ash as a structural material, fly ash was added to concrete constructed in hot and normal environments, and a wall specimen the size of an actual RC structure was manufactured. The manufactured wall specimen compared the depth of carbonation according to the addition rate of fly ash by accelerated carbonation test, and then an exposure test was conducted to examine the corrosion rate of rebars due to carbonation of covered concrete, density of concrete, etc. The density of concrete, corrosion of rebars, and corrosion rate were measured by non-destructive testing, and after the exposure test was completed, the rebar was removed from the wall specimen to calculate the corrosion rate and compared with the non-destructive test results.

2. EXPERIMENTAL PROGRAM

2.1. Mixture proportion

Table 1 shows the combination of concrete and Table 2 shows the materials used. The water binder ratio of all combinations was set at 53%, and FA20-a, FA20-b, and FA20-c, which are combinations with fly ash, replaced fly ash by 20% for cement weight, and FA40-a replaced fly ash by 40% for cement weight. There were three types of fly ash used in this experiment, with density of 2.24 g/cm^3, specific surface parts of a, b, and c of 4000 g/cm^3, 3860 g/cm^3, and 3650 g/cm^3, respectively. The target values of slump and air volume were set at 18±2.5 cm and 4.5±1.5%, respectively.

Table 1. Composition of fresh mixtures

Mixture Composition	NPC	FA20-a	FA20-b	FA20-c	FA40-a
W/B, %	53				
s/a, %	45.0	44.4	44.3	44.4	43.7
Air, %	4.5 ± 1.5				
Water, kg/m^3	185				
Cement, kg/m^3	350	280	280	280	210
Fly ash - a, kg/m^3	-	70	-	-	140
Fly ash - b, kg/m^3	-	-	70	-	-
Fly ash - c, kg/m^3	-	-	-	70	-
Fine aggregate, kg/m^3	763	743	740	745	722
Corse aggregate, kg/m^3	985				
*AE water reducing agent, kg/m^3	4.55(8.05)	4.02(7.52)	4.02(7.52)	4.02(7.52)	3.50(2.45)

* Hot environment inside parentheses, normal environment outside parentheses

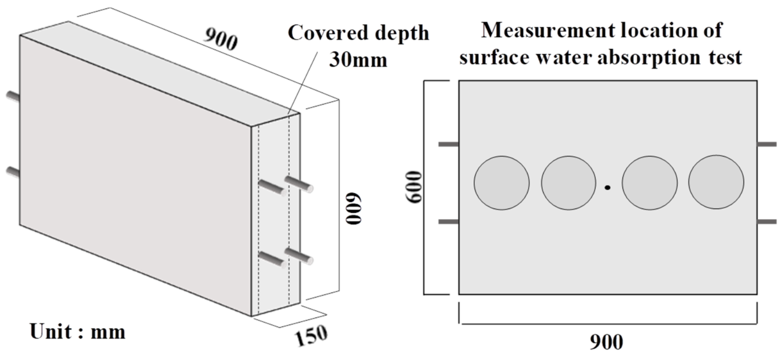


Figure 1. Diagram of a wall specimen

Table 2. Temperature of fresh concrete (℃)

ID	Normal environment	Hot environment
NPC	20.0	34.5
FA20-a	22.0	34.4
FA20-b	22.0	34.0
FA20-c	23.5	33.4
FA40-a	22.5	33.0

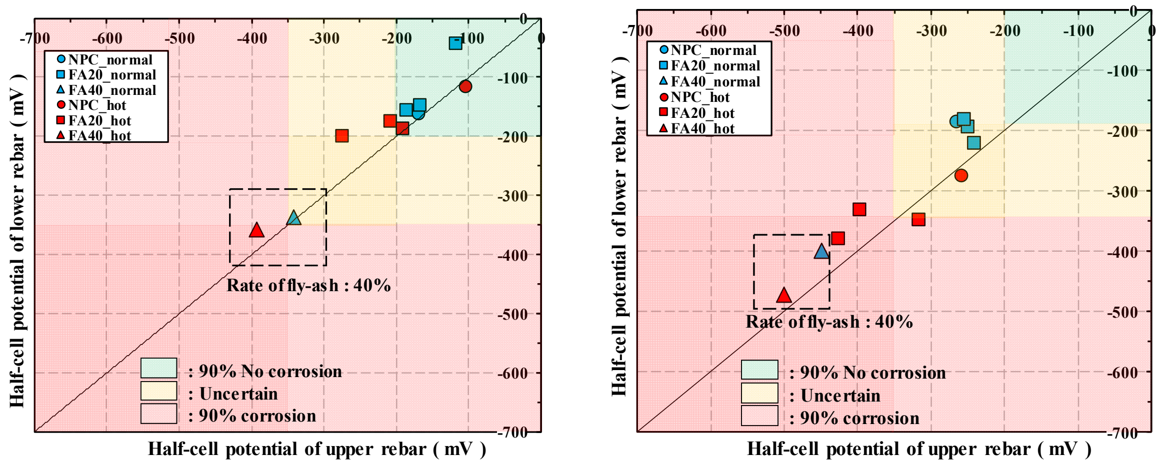
2.2. Preparation and experimental method of test specimen

The wall specimen was placed once each in a normal environment and a hot environment, and in the case of a normal environment, the average temperature was 14.3°C and the maximum daily temperature was 23.5℃ for one month after the test specimen was placed. In the case of a hot environment, the average temperature was 30.0°C and the maximum daily temperature was 38.3°C for one month after the wall specimen was placed. In addition, as shown in Table 2, the temperature of the fresh concrete was 20.0°C to 23.5°C in the case of a normal environment and 33.0°C to 34.5°C in the case of a hot environment.

Figure 1 shows an overview of the wall specimen. The size of the wall specimen was 900mm × 150mm × 600mm, and one rebar was buried in the upper and lower parts, respectively, and the covered thickness of the concrete was 30mm. The rebar exposed to the outside of the wall specimen was finished with epoxy to prevent corrosion during the exposure test.

Photo 1. Wall specimens under exposure test

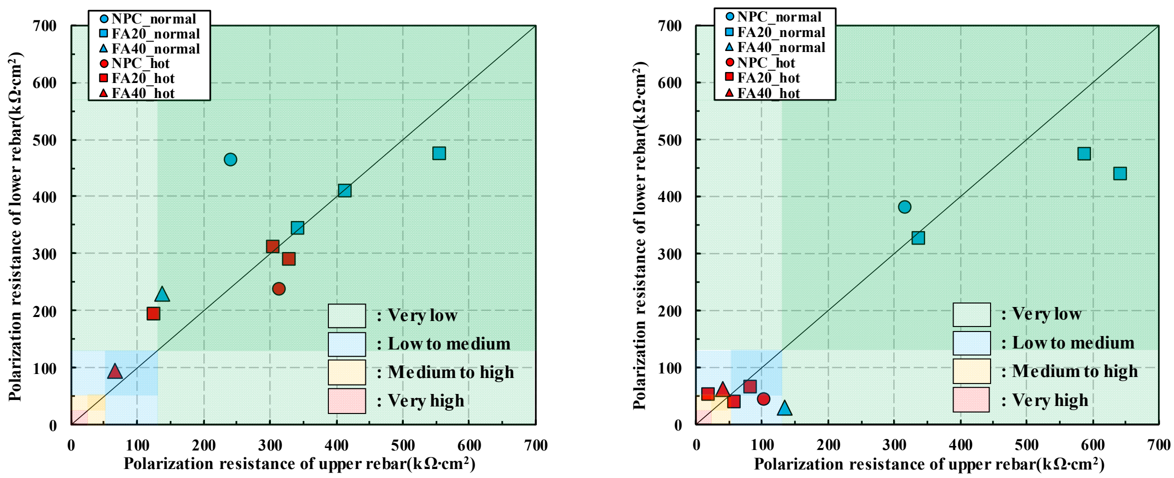
The wall specimen was removed from the mold on the 7th day after in placing and was placed in a laboratory that did not conduct air conditioning until 91 days. The wall specimen was subjected to accelerated carbonation test in a chamber with a carbon dioxide concentration of 10%, and the accelerated carbonation period was about two years. The wall specimen after accelerated carbonation test was exposed outdoors as shown in Photo 1, and the exposure period was about 1.5 years. For the measurement items, the surface water absorption test [7] of concrete, the half-cell potential of rebars, and the polarization resistance of rebars were measured by a non-destructive test method. The surface water absorption test of concrete was measured 91st days after placing, and the measurement location is shown in Figure 1. Measurement of the half-cell potential and polarization resistance were measured twice in total when the accelerated carbonation test was completed (before the exposure test) and when the exposure was completed. The half-cell potential was measured at a total of nine locations at 50mm intervals on the concrete surface to which the rebar was placed for 400mm of buried rebar length near the center of the concrete, and the polarization resistance was measured at two locations for 400mm of the same rebar. In addition, after the exposure test, the depth of carbonation of the concrete was measured, and the rebar was removed from the wall specimen to calculate the corrosion area. For the calculation of corroded rebar area, we first wrapped the rebar with transparent cellophane and marked the corroded area with a marker. Then, we used a software called "IMAGEJ" to calculate the area marked with markers and use it as the area of corroded rebar.



a) Before exposure to the outside

b) After exposure to the outside for 1.5 years

Figure 2. Corrosion probability by half-cell potential of rebars



c) Before exposure to the outside

d) After exposure to the outside for 1.5 years

Figure 3. Corrosion rate by polarization resistance of rebars

The measured value of the half-cell potential was evaluated according to ASTM C876-15 [8], and the measured value of the polarization resistance was evaluated according to CEB recommendation [9].

3. RESULTS AND DISCUSSION

3.1. Changes in half-cell potential and polarization resistance values before and after exposure of rebars inside wall specimens

As shown in Figure 2.a), NPC and FA20 are included in the "90% No corrosion" range for pre-exposure normal environments, NPC is included in the "90% No corrosion" range for hot environments, and FA20 is included in the "Uncertain" range.

On the other hand, in the case of FA40, the half-cell potential value of FA40 constructed in a normal environment is -339.3mV, which is close to the "90% corrosion" area, and FA40 constructed in a hot environment corresponds to the "90% corrosion" area even before exposure.

According to Nishikigi's study[10], even if concrete using fly ash is carbonated, the rebar does not corroded without moisture supply. However, in this experiment, the half-cell potential measurement result of the reinforcement of the FA40 test specimen showed that the half-cell potential value corresponds to "90% corrosion" even though there was no supply of water and moisture in the air. I would like to make this a future task.

Figure 2.b) shows the results of measuring the half-cell potential of rebars after exposing the wall test specimen outdoors for about a year and a half. Compared to the results of the exposure, the potential was lowered and in particular, the half-cell potential value of the rebar of the wall specimens constructed in a hot environment was significantly reduced. The half-cell potential value of rebar of the wall specimens constructed in a normal environment moved out of the "90% No corrosion" area to the "Uncertain" area, and the half-cell potential value of rebars of wall specimens constructed in a hot environment moved to "90% corrosion", except for NPC in the "Uncertain" area.

Figure 3 shows the results of polarization resistance measurement before and after exposure of the rebar of the wall specimens. As shown in Figure 3.c), the polarization resistance value of rebar of all specimens, except for FA40 constructed in hot environments, is measured high and corresponds to the "Very low" area. After the exposure test, as shown in Figure 3.d), the corrosion rates of NPC and FA20 except for FA40 remained almost unchanged in normal environments, but in hot environments, the polarization resistance values of all specimens decreased significantly and moved to the "Low to medium" and "Medium to high" areas.

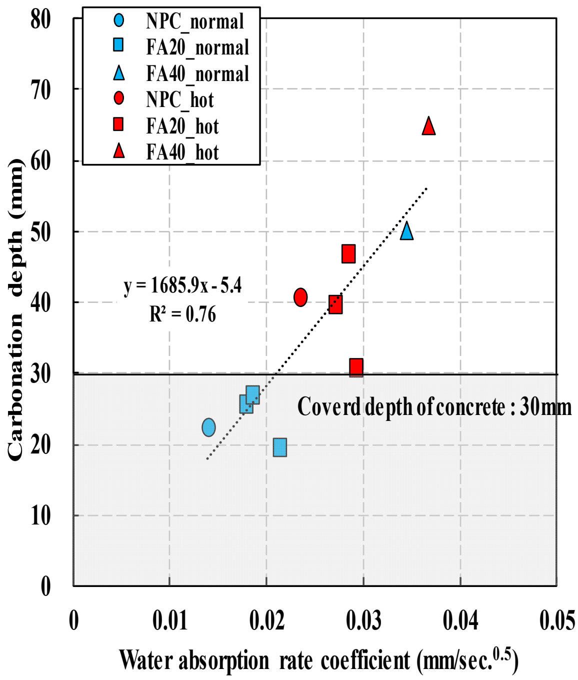


Figure 4. Relationship between water absorption rate coefficient and carbonation depth

3.2. Measurement results of surface water absorption test and carbonation depth

Figure 4 shows the relationship between the surface water absorption test results of the wall specimen measured the 91st day after the wall specimen is placed (before the start of the accelerated carbonation test) and the depth of carbonation after the exposure test of the wall specimen was measured. As can be seen from the figure, the water absorption rate coefficient and the depth of carbonation are in a linear relationship. The water absorption rate coefficient increases as the addition rate of fly ash increases, and the water absorption rate coefficient of wall specimens placed in a hot environment tends to be greater than the water absorption rate coefficient of wall specimens constructed in a normal environment. Likewise, the depth of carbonation was greater than the depth of carbonation of the wall specimen constructed in a hot environment. Also, basically, the depth of carbonation seems to increase as the replacement rate of fly ash increases, but depending on the type of fly ash, the depth of carbonation of FA20 is similar to that of NPC or less than that.

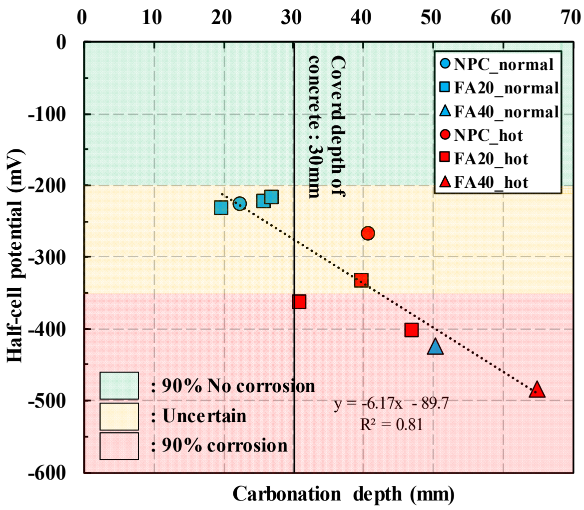


Figure 5. Relationship between carbonation depth and half-cell potential of rebar

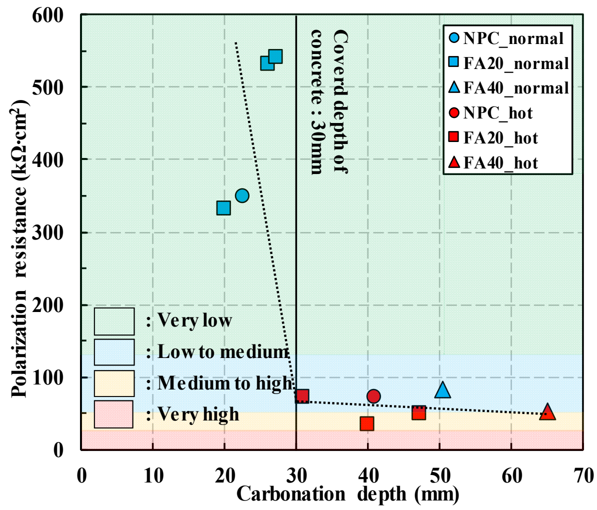


Figure 6. Relationship between carbonation depth and polarization resistance of rebar

3.3. Effect of concrete surface density on corrosion of Rebar (Comparative analysis of each test result)

Figure 5 shows the relationship between the carbonation depth of the wall specimen and the half-cell potential of the rebar of the wall specimens after the exposure test is completed. As shown in Figure, as the depth of carbonation increases, the half-cell potential value decreases linearly. NPC and FA20 have the almost same half-cell potential value in a normal environment, but the half-cell potential value of rebars in a hot environment is becoming very small because covered concrete is carbonized more than 30mm.

Figure 6 shows the relationship between the carbonation depth of the wall specimen and the polarization resistance value of the rebar of the wall specimen after the exposure test is completed. Except for FA40, the corrosion rate of NPC and FA20 is very slow in the case of wall specimens constructed in a normal environment, and the corrosion rate of wall specimens constructed in a hot environment has been relatively fast. As can be seen in the figure, since NPC and FA20 placed under normal environments are not carbonated until the concrete cover thickness, the corrosion rate is very slow, but the moment the carbonation depth exceeds the concrete cover thickness of 30 mm, the corrosion rate of the rebars (regardless of the combination) increases greatly.

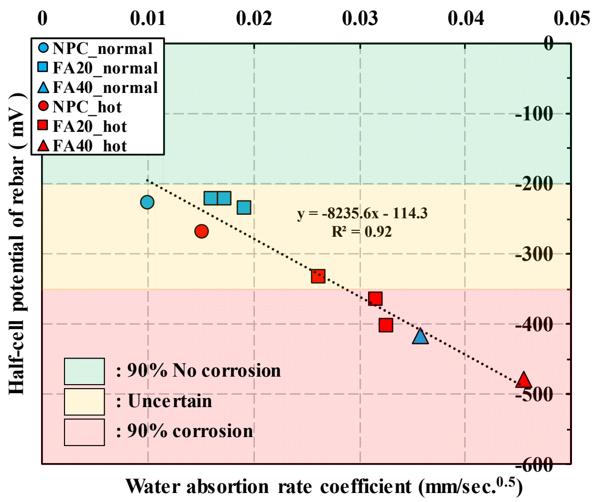


Figure 7. Relationship between water absorption rate coefficient and half - cell potential of rebar

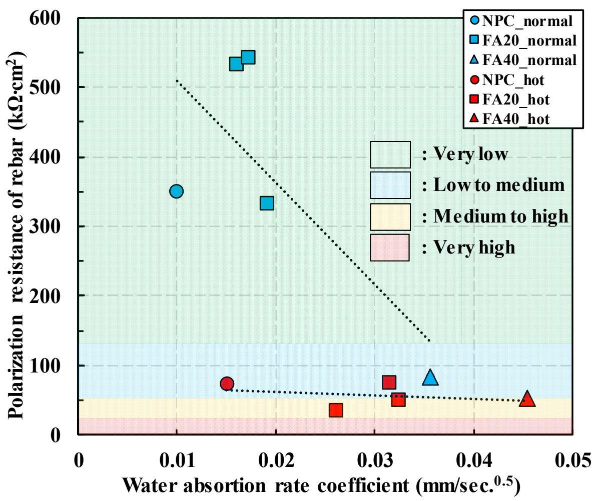


Figure 8. Relationship between water absorption rate coefficient and polarization resistance of rebar

Figure 7 shows the relationship between the water absorption rate coefficient of the wall specimens and the half-cell potential of the rebar after the exposure test is completed. As the water absorption rate coefficient of the wall specimen increases, the half-cell potential value of the rebar decreases, indicating that the density of the concrete surface influences the corrosion of the rebar inside the concrete. Figure 8 shows the relationship between the water absorption rate coefficient of the wall specimen and the polarization resistance value of the rebar after the exposure test is completed. As the water absorption rate coefficient of the wall specimen increases, the corrosion rate increases, but as shown in Figure 6, the polarization resistance value changes rapidly depending on the carbonation of the cover concrete.

Because penetration of carbon dioxide, one of the direct factors that corrodes rebar, depends on the density of the cover concrete, and half-cell potential, which evaluates the corrosion rate of rebar, also varies depending on the density of the cover concrete, the water absorption rate coefficient that evaluates the density of cover concrete is also considered to have a good correlation with carbonation depth and half-cell potential.

rebar is located. In other words, since the polarization resistance value of the passivation film is very high, the polarization resistance value when the passivation film is present and when it is not present is very different.

Therefore, the measurement of half-cell potential value is appropriate when determining the current degree of corrosion of rebar, and the measurement of polarization resistance is considered effective when determining whether the rebar's passivation film exists or is destroyed.

Figure 9 shows the corrosion area rate of the rebar removed from the wall specimen after the exposure test is completed. As the addition rate of fly ash increases, the corrosion area of rebars increases, and the corrosion area rate of wall specimens placed in hot environments is more than twice that of the corrosion area placed in normal environments. On the other hand, regardless of the period of construction, the corrosion area ratio of FA40 exceeds 90%. In addition, as shown in Figure 10, the half-cell potential value of the rebar measured by the non-destructive test and the corrosion area ratio of the rebar has a very high correlation coefficient of 0.97, so it can be said that the estimation of the corrosion rate by non-destructive test is value.

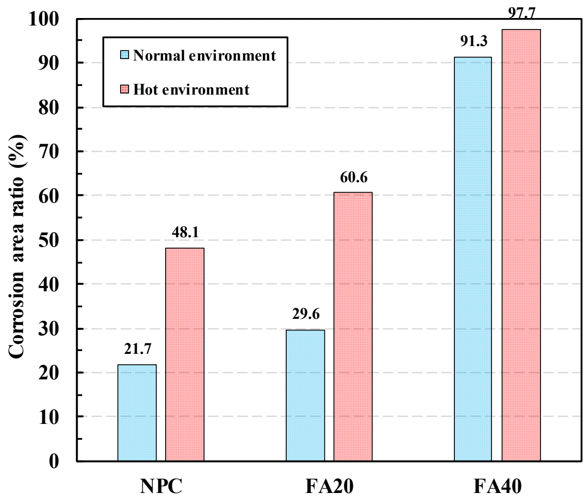


Figure 9. Corrosion area ratio of rebar

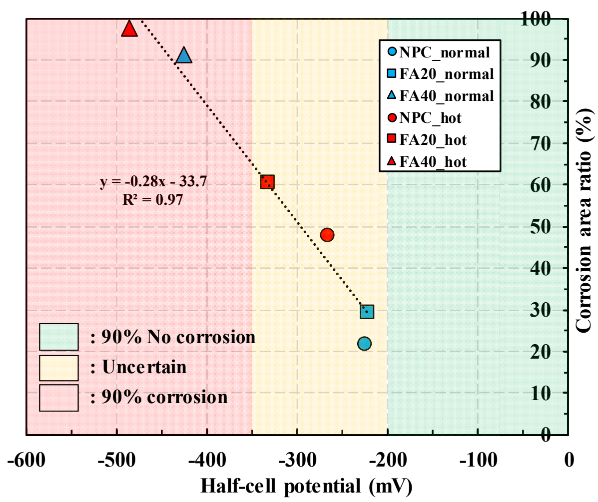


Figure 10. Relationship between half-cell potential and corrosion area ratio

On the other hand, since the polarization resistance value is to evaluate the corrosion speed of the rebar, the corrosion speed is highly evaluated for the rebar that has already been corroded to some extent, while the corrosion rate is very low when the concrete is not carbonized to the position where the

4. CONCLUSION

The density of the surface of the wall specimen placed in a hot environment is lower than that of the normal environment, so the rate of carbonation is accelerated. The tendency accelerates as the replacement rate of fly ash increases, but the depth of carbonation in the normal environment is similar to that of NPC up to 20% of the replacement rate of fly ash, and the half-cell potential value and polarization resistance value of rebars were the same or higher. In general, it is known that the addition of fly ash to concrete increases the carbonation rate, but in the scope of this study, the same level of concrete quality as NPC was achieved up to 20% of the addition rate of fly ash. On the other hand, if the addition rate of fly ash is excessive, the depth of carbonation of concrete increases regardless of the environment, and the corrosion rate of rebars increases very fast.

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