Corrosion of steel bar embedded in mortar specimens exposed in different environmental conditions for 8 years

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1. Introduction

Chloride-induced corrosion is one of the main mechanisms of deterioration affecting the long-term performance of concrete structures. The physical protection by concrete is provided by its dense structure which retards the ingress of aggressive species, such as oxygen, moisture and chloride ions to the steel-concrete interface. This investigation was carried out to study the effect of chloride ion and carbonation [1] on the corrosion of steel in reinforced mortar specimens with different environmental conditions exposed for 8 years. Using these results, we investigated the effect of admixture and the influence of exposure environment on corrosion of steel.

2. Outline of Experiment

2.1 Materials and Mix Proportion

The physical properties of material and mix proportion of concrete are shown in **Table 1** and **Table 2**. Ordinary Portland cement and standard sand of fine aggregate were used for specimens A, N and Y. In addition, specimens B-A, B-B and B-F used the mixture of Ordinary Portland cement and BFS. Round bar SR235 with the length of 50 mm was embedded at the center of the specimen. The steel bar was immersed in ammonium citrate solution beforehand and after removing the black skin, copper wire was passed through the end of the reinforcing bar for measurement of electric potential.

2.2 Specimens design

Fig.1 shows the specimen design. Ø9 mm diameter of steel bars with 50mm exposed length was embedded inside concrete. As shown in the figure, the upper and bottom surface of the specimen were covered by epoxy resin, to prevent the ingress of substances to the lateral surface.

2.3 Curing condition

After 24 hours from mortar casting, specimens were demolded and were cured in tap water for 1 month. After 1-month material age, exposure test was started. Specimens were placed in different environmental places for 8 years as shown in **Table 3**. Here, Kagoshima is “sulfate condition”, Okinawa is “chloride condition”, and Kyushu University is “carbon dioxide condition”.

2.4 Method of evaluation

After 8 years of continuous exposure, the specimens were transferred from the exposure site to the laboratory. The specimens were investigated for the corrosion evaluation of steel bar. Measurements were conducted by taking the half-cell potential, polarization curve, and actual corrosion test. The probability of corrosion was estimated by following ASTM C876 standard.

3. Results and Discussion

3.1 Half-cell potential (HCP)

By using the saturated method the half-cell potential

Table1. Physical properties of material

Material	Description
Cement	Ordinary Portland cement Density = 3.16 g/cm^3, SSA = 3350 cm^2/g
BFS	Ground granulated blast furnace slag 4000 Density = 2.90 g/cm^3, SSA = 4000 cm^2/g
Sand	Toyoura standard sand Density = 2.65 g/cm^3
Steel bar	Round bar SR235 Ø = 9mm
Water	Tap water

Table2. Mix proportion

Specimens ID	W/B %	Unit Weight (kg/m^3)			
		Water	Cement	BFS	Sand
A	50	334	668	0	1202
N		334	668	0	1202
Y		334	668	0	1202
B-A		334	334	334	1179
B-B		334	334	334	1179
B-F		334	334	334	1179

Table3. Exposure sites of specimens

Specimens ID	Exposure location
A	Kagoshima (Kirishima Hot spring)
B-A	
N	Okinawa (Coastal area)
B-B	
Y	Air curing room at laboratory at Kyushu University
B-F	

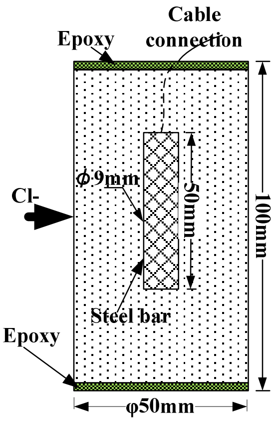

Fig.1 Specimen details

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(HCP) was carried out by immersing the specimen in tap water for 30 to 40 minutes. **Fig.2** shows the HCP of steel bars in concrete with the carbonation depth by phenolphthalein. It is found that the specimens contain BFS in its recorded more negative values compared with OPC mixed specimen at the same exposure site.

3.2 Carbonation depth

Carbonation depth is also shown in **Fig.2.** It can be observed that the large carbonation depth was for B-F and B-B specimen.

3.3 Polarization curve

Anodic polarization curve was measured by the immersion method after exposure. It was measured to evaluate the condition of passivity film on the steel surface. **Fig.3** and **Table 4** indicates the anodic polarization curve and the grade of passivity of steel bars [2]. Only specimens exposed in air condition (Y, B-F) shows relatively lower grade, the grade 2 and 3. Others are categorized in relatively good grade 4 and 5, which states that the certain passivity condition exists [2].

3.4 Corrosion rate

After splitting the specimens the steel bars were extracted from concrete as shown in **Fig.4**. **Table 4** shows the corrosion rate of steel bars after extraction. The max corrosion rate was recorded for the specimens with OPC which were stored in air curing room at Kyushu University. For B-A and B-B, corrosion rate is over 50%, however, the grade of passivity is 5 and 4, respectively. This disagreement cannot be explained clearly, but it is expected that this is due to BFS mix for mortar mixing.

4. Conclusion

Based on the exposure test and experimental work results, under the condition that is cover depth is 20mm, exposure duration is 8 years, following conclusion can be drawn:

(1) The values of HCP of the steel bar embedded in BFS mixed mortar is more negative than that of OPC mixed mortar.

(2) The values of HCP of the steel bar exposed in air drying condition was most negative compared with other exposure conditions.

(3) For the passivity condition of the steel bar, it can be said that the most severe condition is air curing, which accelerates the carbonation of cover mortar.

(4) As for the specimen exposed in sulfate and chloride conditions, the corrosion was slight and still in good condition after 8 years exposure.

(5) For the specimen mixed with BFS, the disagreement between corrosion rate and the grade of passivity was found, possibly due to BFS.

References

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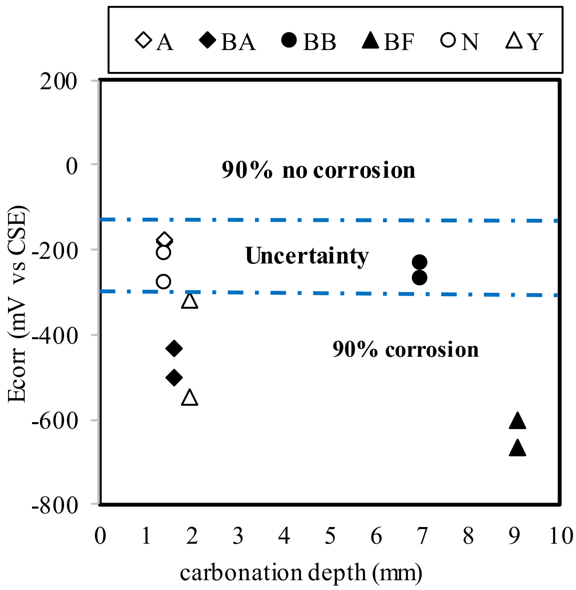

Fig.2 Half-cell potential vs. carbonation depth

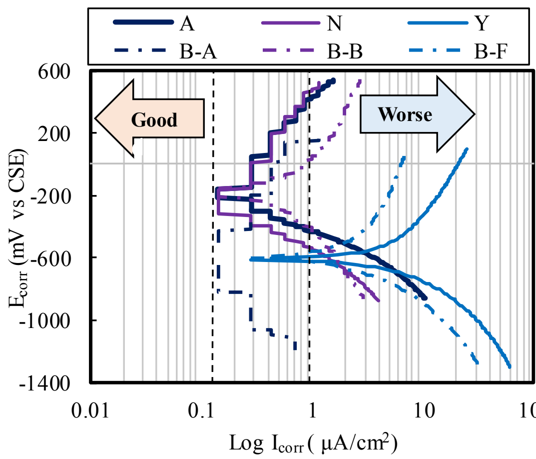

Fig.3 Polarization curve

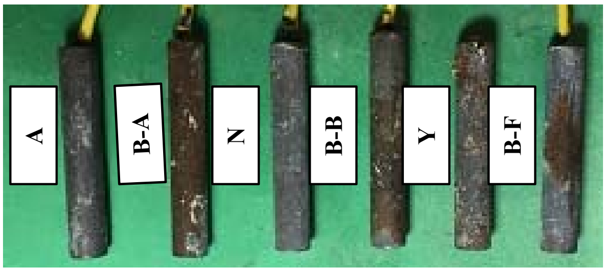

Fig.4 Steel bars after extraction

Table4. Corrosion rate of steel bars after extraction

Specimens ID	Total Area	Corrosion Area cm^2	Corrosion rate%	Passivity Grade
A	14.13 cm^2	0	0	4
B-A		7.48	52.94	5
N		0.88	6.23	4
B-B		8.22	58.17	4
Y		9.81	69.15	2
B-F		3.36	23.77	3