EFFECTIVENESS OF MARINE AQUATIC ORGANISM AS CONCRETE SURFACE COVER ON CHLORIDE INGRESS INTO CONCRETE

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1. Introduction

After several years of exposure in marine environment, concrete structure often found that marine aquatic organism layer adhered on the surface. Marine aquatic organism layer is possible to prevent chloride ions from ingressing into the concrete as the main cause of reinforced steel corrosion. However, there were few researches that would be done in this study to know the effect of marine aquatic organism layer as concrete surface cover. In order to know the effect of marine aquatic organism layer of concrete durability, the experiments were carried out in this research, to measure the effective diffusion coefficient, apparent diffusion coefficient, corrosion of steel area and microstructure by SEM.

2. Methodology

2.1 Material and Mix Proportion

Four samples which had been exposed Shimizu Port at Shizuoka Prefecture, Japan were tested. **Table 1** shows physical properties of material.

Table 1 Physical Properties

Material	Type	Physical Properties		F.M.
		Density (g/cm^3)	SSA (cm^2/g)	
Cement	OPC	3.15	3396	-
BFS	BFS 4000	2.87	4270	-
FA	Class II (JISA6201)	2.20	3380	-
Sand	River sand	2.58	-	2.77
Gravel	Crushed Gravel	2.71	-	6.97

The mix proportions are shown in **Table 2** with water to cement ratio (w/c) of 40% and 55%. Samples have been kept in marine environments for 13 years. Reinforced concrete (RC) specimens with dimensions of 100 mm x 100 mm x 400 mm were prepared for exposure test. Cement paste cubic with size of 150 mm was also exposed for microstructure analysis by SEM. During 13 years exposure in the marine environment, marine aquatic layer formed on the surface of concrete. **Fig. 1** shows covering marine aquatic layer on the surface of concrete.

Table 2 Mix Proportions

No	W/C	Unit Weight (kg/m³)						
		W	C	BFS	FA	Sand	Gravel	Water reducer
Mix A	0.55	176	320	-	-	793	986	0.8
Mix B	0.55	176	176	144	-	765	986	0.8
Mix C	0.55	176	220	-	96	748	986	0.8
Mix D	0.40	170	420	-	-	748	986	1.05

2.2 Testing Procedure

a. Scanning electron microscope (SEM)

In quality assurance of concrete, scanning electron microscope provides important information about properties of concrete which related to microstructure.

b. Effective diffusion coefficient, D_e

Effective diffusion coefficient by migration test is considered as an important parameter in order to know the amount of chloride ingress into concrete. The negative charge of chloride ions migrate from the cathode toward the anode. The chloride ion content in the anode cell was measured after steady state is reached according to JSCE-G571-2003.

There are two procedures used in this migration test. First, sample with the presence of marine aquatic organism on the concrete surface were set up to the cathodic side and D_e was measured. Second, using the same sample, the marine aquatic organism was removed by grinding machine. Then samples were set up for the same migration test procedure.

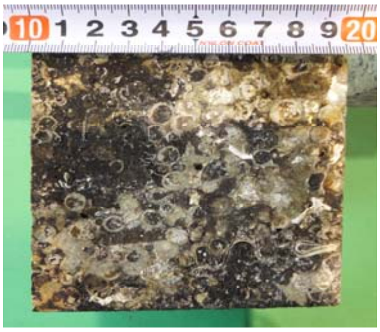

Fig. 1 Marine aquatic organism layer (Covered area = 99.79%; Mix B)

c. Apparent diffusion coefficient, D_a

The amount of chloride ion content penetrated into each layers from the outer surface of reinforced concrete were determined by apparent diffusion coefficient (D_a). Sample was cut to four layers from the surface of concrete, with 10 mm thick for each layer. Then chloride ion concentrations were measured by potentiometric titration.

d. Corrosion of steel bar

Reinforced steel embedded in concrete was drawn out. The surface of reinforcing steel bar was covered by OHP sheet and the area of steel corrosion was marked. Finally, percentage of corrosion area to all area was calculated.

2.3 Test Result

a. Scanning Electron Microscope

Backscattered Electron Image from SEM is shown in **Fig. 2**. The figure presented 50μm thickness of marine aquatic organism layer. From the figure it can be seen that the layers of marine aquatic organism is very dense, hence it's provides adequate protection to the concrete from chloride penetration and dissolved oxygen.

b. Effective diffusion coefficient, D_e

Fig. 3 shows the result of D_e from migration test. It can be seen that marine aquatic organism has potential to reduce the rate of chloride ion migration into the concrete for all sample. For concrete using OPC showed that the value of the diffusion coefficient increased as increasing of w/c. On the other hand, concrete by using partial replacement of

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cement with 40% BFS (Mix B) showed increasing impermeability for the same w/c of 55%. Moreover, this also occurred for concrete with partial replacement of cement by Fly Ash of 30%. It can be concluded that partial replacement of cement by 30% FA shows the lowest value of diffusion coefficient compared than the other.

In addition, the effect of marine aquatic organism layer as concrete surface cover showed effectiveness on diffusion coefficient. **Fig. 3** shows clearly difference in effective diffusion coefficient with and without marine aquatic organism layer as concrete cover. It appears that marine aquatic organism layer as concrete cover could reduce the value of effective diffusion coefficient. Effectiveness of covering marine aquatic organism layer for effective diffusion coefficient in percentage obtained: 32.8% for Mix A, 26.3% for mix B, 58.8% for mix C and 13.1% for mix D.

c. Apparent diffusion coefficient, D_a

Fig. 4 shows the result of D_a and chloride distribution. Mix C gave the lowest Da value followed by mix B, mix D and lastly mix A. Mix without mineral admixture did not have any positive reaction towards chloride ion penetration even though lower w/c was used. Again, FA shows remarkable result on D_a measurement.

d. Corrosion area of steel bar

Table 3 shows the percentage of corrosion area of steel reinforcement embedded in concrete. The corrosion area on the steel surface was detected on the steel reinforcement embedded in mix A. High apparent diffusion coefficient leads to high amount of chloride penetrated into the concrete. Mix D was also included high chloride concentration. However, steel corrosion didn't occur. This result was considered as marine aquatic organism layer prevented diffusion of oxygen. On the other hands, partial replacement of cement by BFS and FA (Mix B and C) did not show the corroded area. **Fig. 5** shows actual corrosion condition reinforced steel embedded in concrete.

Table 3 Corrosion condition and corroded area

Name	Cover thickness (mm)	Corrosion area (%)	Corrosion stage 
Mix A	40	17.87	
Mix B	40	0	
Mix C	40	0	
Mix D	40	0	

3. Conclusion

Marine aquatic organism, different level of water cement ratio and partial replacement of cement (Blast Furnace Slag and Fly Ash), affected the durability and chloride ion ingress into the concrete. Based on the investigation, the following conclusions are drawn:

1. Marine aquatic organism layer is very dense from SEM observation, so it can prevent chloride penetration thus improved the durability of the concrete.
2. The effect of marine aquatic organism layer as concrete surface cover showed effectiveness on chloride diffusion coefficient.

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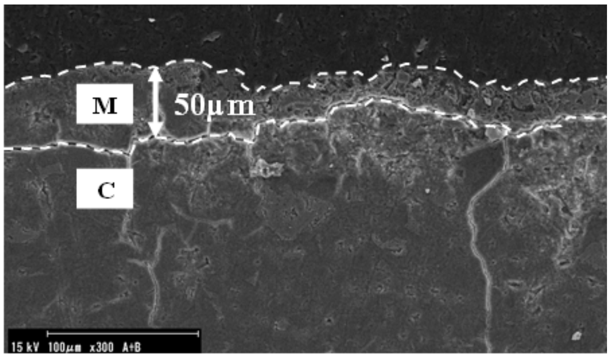

M-Marine aquatic organism layer; C-Cement paste; T-Thickness 50µm

Fig. 2 SEM observation for mix D w/c=0.40

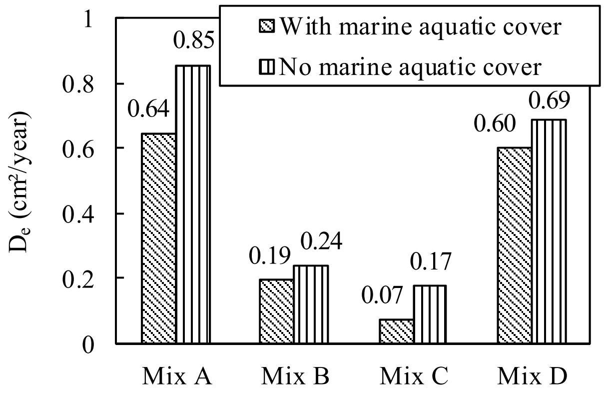

Fig. 3 Effective diffusion coefficient, D_e (cm^2/year)

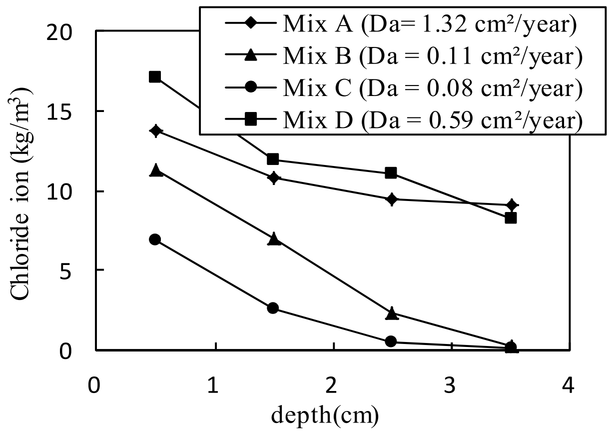

Fig. 4 Chloride distribution and calculated apparent diffusion coefficient, D_a (cm^2/year)

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