B-1-2 Effect of combination of slicate based penetrant material and reaction accelerator on quality of concrete

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ABSTRACT: Silicate based surface penetrant material is used to improve durability of concrete structures. Silicate based penetrant material is ineffective when calcium ions are less available, such as in neutralized concrete or concrete with fly ash or slag cement. As a counter-measure, combination of penetrant material and calcium based reaction material is tried. In this study, in order to confirm the effect of such combination, accelerated carbonation test and salt immersion test are performed on concrete applied with both the materials. It is found that the combination has high performance compared with the traditional method on blended concrete. It is also observed that the combination produces a reaction product capable of densifying concrete and immobilizing free chloride ions in concrete, thereby suppressing neutralization and chloride penetration.

KEY-WORDS: Silicate based surface penetrant material, neutralization depth, chloride ion

INTRODUCTION

Silicate based surface penetrant materials (SPM) have been applied for maintenance and improvement of durability of concrete. They are easy to apply on concrete suface (Fig.1). SPM can fall into two main catefories, (i)solidifying type and (ii) reaction type. In the case of solidifying type, SPM reacts with water and calcium ion to produce C-S-H crystal and the unreacted material solidifyies by drying. On the other hand, in case of reaction type, this material reacts with water and calcium ion in concrete to form C-S-H crystal and the unreacted material when exposed to water reacts again with calcium ion in concrete pores. However, both types are inefficint if calcium ions are scarce. This condition occurs with fly ash or slag cement where calcium ions are reduced by pozzolanic reaction and/or neutralizaion. Therefore, combination of SPM and calcium based reaction material (CRM) is epected to solve the problem. And, the effect of combination method on improvement of durablity may depend on amount applied.

Fig.1. Situation of SPM applied to actual structures

Firstly in this study, accelerated carbonation test and salt immersion test were performed for different amounts of combination of SPM and CRM. Secondly, it was considered that performance of combination depends on moisture content of concrete when applied. Therefore, the durability improvement of concrete depending on moisture content was examined by accelerated carbonation test.

EXPERIMENTAL PROGRAM

Effect of amount of surface materials applied on the durability of concrete

Materials and methods

Main constituents of SPM are silicate, Na (sodium) and K (potassium) with pH exceeding 11. CRM was used with pH exceeding 12. Initially both the materials were mixed in a plastic beaker to observe any change due to chemical reaction. It showed gradual reaction after about 12 hours of mixing. It was a homogeneous reaction product as shown in Fig. 2.

Fig.2. Reaction products after mixing SPM and CRM

Preparation of specimen and application of SPM and CRM

Portland blast furnace cement was used for concrete with crushed stone of nominal maximum size of 20mm as coarse aggregate and sea sand as fine aggregate. Table 1 shows the mix proportion of concrete. Concrete prism specimens of 10×10×40cm^3 were prepared and cured in water for 28 days. After curing, specimens were cut into cubes of 10×10×10cm^3 and were wrapped in aluminum tape except test surface as shown in Fig.3.

CRM was applied initially, and after 24 hours, SPM was applied. After CRM and SPM were applied on the concrete surface, specimens were kept standing at temperature of 20^{0}C, humidity 60% for 1 day. Amount of each material was 0.05g/cm^2 (referred as "AH"), 0.075g/cm^2 (referred as "AH×1.5"), 0.1g/cm^2 (referred as "AH×2.0"). For comparison, specimen applied with only SPM was prepared (referred as "A").

Table 1. Concrete mix proportion

Specimen	W/B (%)	s/a (%)	Unit content (kg/m³)					
			W	C	S	G	AE1	AE2
BB	55	47	165	300	880	987	4.28	1.14

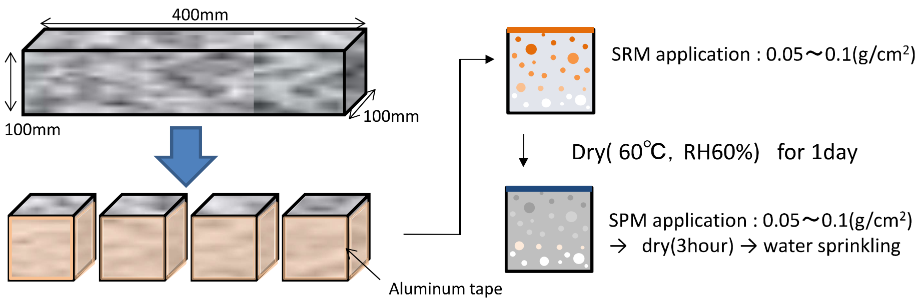

Fig.3. Application method of surface materials

Penetration depth

Penetration depth of SPM was measured by ion chromatography. The distribution of sodium and calcium ions in the specimens were measured using drill-sample of concrete (0.3g of drilled powder mixed with 29.7g ultra-pure water).

Accelerated carbonation test

The accelerated carbonation test was carried out under temperature of 20^{0}C, relative humidity of 60% and concentration of CO_2 maintained at 5% for 28, 56 and 91 days. Neutralization depth was measured by spraying phenolphthalein solution on cut section of the specimen.

Salt immersion test
For salt immersion test, specimens were immersed in 3% NaCl solution for 91 days. After immersion for 91 days, chloride ion content at regular depth intervals was measured. Both total chloride and soluble chloride contents were determined.

Effect of moisture content in concrete

Specimens
In this experiment, $10\times10\times10cm^3$ cubic specimens were made of mortar with 55% of water cement ratio. As for mortar specimens, Portland blast furnace cement was used and specimens were cured in two different conditions; water and atmosphere, for 28days, respectively.

Fig.4 shows the procedure for preparing the specimen. Concrete specimens are divided into three groups subjected to different conditions for a period of 2days after initial curing for 28 days, such as “oven dry condition”, “atmospheric condition” and “immersion in water condition”, to adjust initial moisture content of specimens approximately to 0%, 50% and 100% for concrete. These moisture contents of specimens were calculated by Eq.(1).

$$\text{Moisture content (\%)} = (a - b)/(c - b) \times 100 \quad (1)$$

a: Mass of the specimen for surface material application
b: Mass of absolute dry specimen
c: Mass of saturated specimen

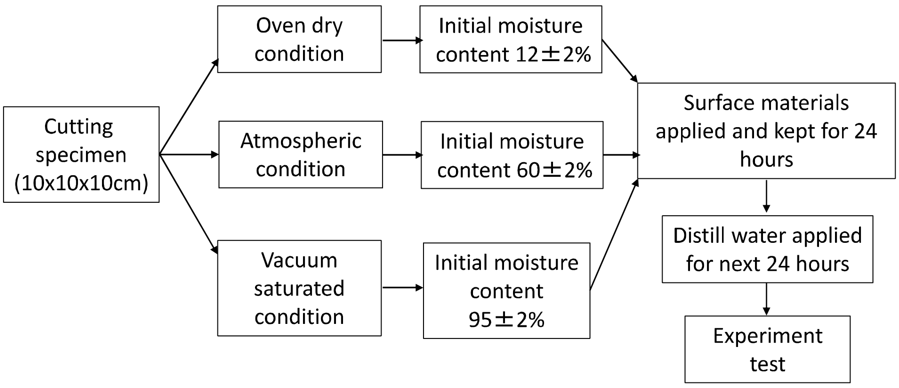

Fig.4. Procedure to prepare the specimens

CRM was applied initially, and after 24 hours, SPM was applied. After applying both SPM and CRM on the concrete surface, specimens were kept standing at temperature of 20^0C, humidity 60% for 1 day. Amount of each material was $0.05g/cm^2$ (AH), $0.075g/cm^2$ (AH×1.5), $0.1g/cm^2$ (AH×2.0). For comparison, specimen applied with only SPM (“A”) was prepared.

Accelerated carbonation test
The accelerated carbonation test was carried out under temperature of 20^0C, relative humidity of 60% and concentration of CO_2 maintained at 5% for 28, 56 days. Neutralization depth was measured by phenolphthalein solution spraying method.

RESULTS AND DISCUSSION

Fig.5 shows the penetration depth of surface materials in the specimens. Penetration depth of SPM was about 4.2mm, AH with both SPM and CRM was 6.5mm. From this result, it found that penetration depth increased by using CRM. Although this phenomenon is not clearly understood, CRM is thought to penetrate deeper than SPM due to the lesser viscosity of the former. Hence, SPM possibly penetrated deeper due to the reaction with penetrated SCM. In the case of increased application amount, penetration depth of AH×1.5 and AH×2.0 was 7.5mm and 15mm, respectively. The materials penetrated deeper as the amount of applied surface materials increased.

Fig.6 shows the neutralization coefficient of specimens. Neutralization coefficient of “without coating” specimen was 25mm/year and with SPM only was 19mm/year. On the other hand, neutralization coefficient of AH, AH×1.5, and AH×2.0 were 17mm/year, 14mm/year and 12.5mm/year, respectively. The combination improved concrete resistance to neutralization in comparison with existing method such as SPM application. Existing method of SPM application alone showed no effect on improvement of concrete surface even if amount increased. However, in this method, it was found that the effect of combination method increased with increasing application amount.

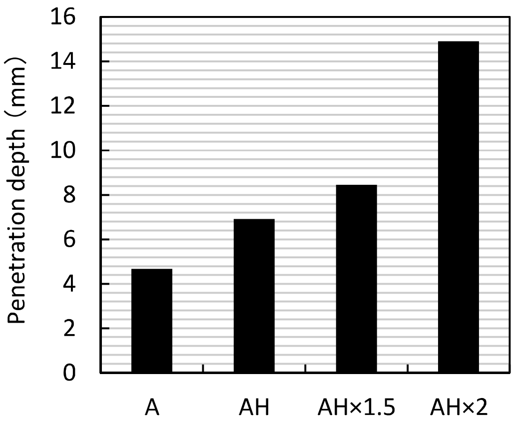

Fig.5. Penetration depth of specimens

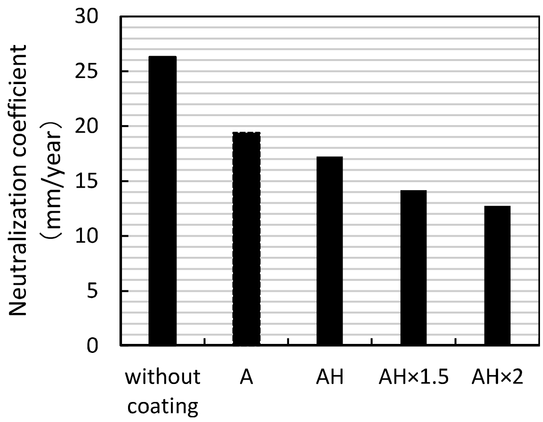

Fig.6. Neutralization coefficient of specimens

As an example, Fig. 7 shows the pore distribution of concrete surface up to a depth of 1cm by mercury intrusion technique. It was confirmed that pore volume of AH×1.5 reduced between pore diameter range of 20nm to 50nm compared to AH. This showed the effect of higher amounts of combination of surface penetrants.

Fig.8 shows the distribution of total chloride ion content in specimens. Improvement of resistance to chloride ion was not confirmed in combination method regardless of application amount. Fig. 9 shows the distribution of soluble chloride ion which is said to directly influence corrosion of rebar. Soluble chloride ion content in “A” was not different from “without coating” specimens. On the other hand, in case of combination method, soluble chloride ion decreased with increasing application amount. And, when the AH×1.5 and AH×2.0 was applied, soluble chloride ions were significantly reduced at 30mm depth from surface. From this result, it was considered that chloride ion reacted chemically or bound physically by the reaction products of SPM and SCM, and part of the penetrated chloride ion was immobilized.

Combination of SPM and SCM assured improvement of durability in the case of low calcium conditions found in concrete using blast furnace cement and fly ash. And, this method also showed improved performance with higher application amount.

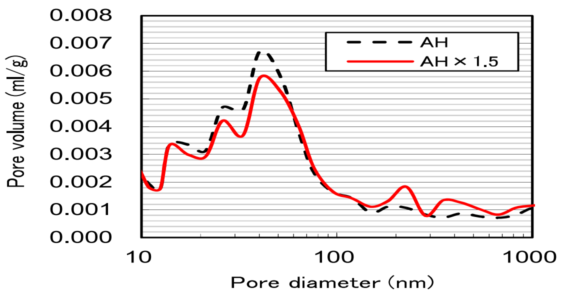

Fig.7. Pore distribution up to 1cm portion from surface

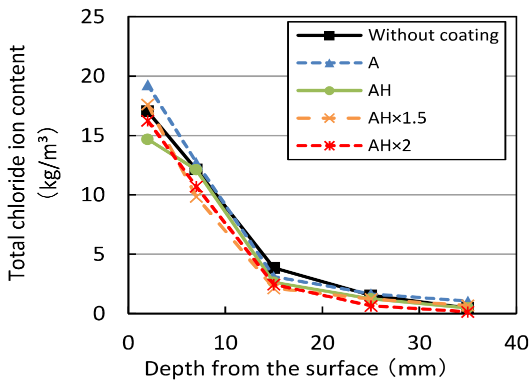

Fig.8. Distribution of total chloride ion content

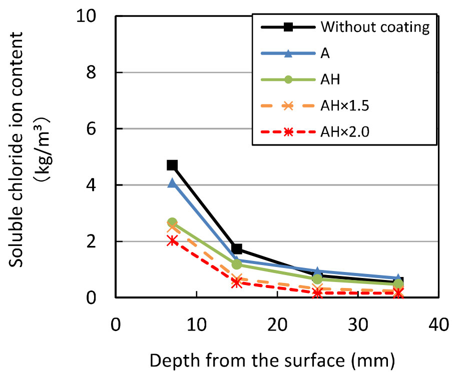

Fig.9. Distribution of soluble chloride ion content

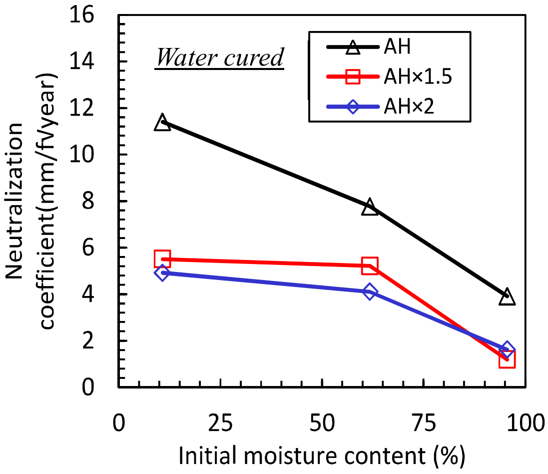

Fig.10. Relationship between neutralization and initial moisture content (water cured)

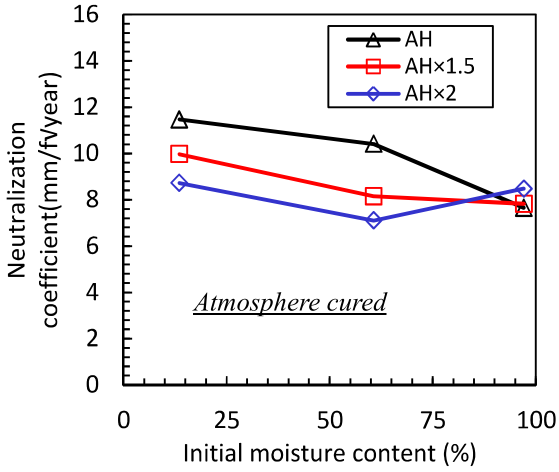

Fig.11. Relationship between neutralization and initial moisture content (atmosphere cured)

Fig.10 shows the difference in neutralization coefficient for water cured mortar when subject to each initial moisture content. Neutralization coefficient tends to decrease with increasing initial moisture content in spite of applied amount. Neutralization coefficient was low for higher applied amount in the case of initial moisture content up to 60%.

At higher moisture content of mortar, difference between AH×1.5 and AH×2.0 was not observed. It is attributed to the fact that at high initial moisture content in mortar, CRM was kept in water filled pore in mortar and was protected from drying. It provided a conductive environment for SPM to react with CRM. This result was similar when only SPM was applied to concrete subject to different moisture content [4].

Fig.11 shows the difference in neutralization coefficient for atmosphere cured specimens. Neutralization coefficient tends to decrease with increase in both initial moisture content and applied amount same as that of water cured specimen. However, at low initial moisture content in mortar, atmosphere cured specimens showed higher neutralization. It was assumed that penetration depth of CRM was deep due to the atmosphere cured specimen being porous in comparison with water cured specimens. However, less moisture content did not facilitate the penetration of CRM to deeper sections and reaction between SPM and CRM, and the CO_2 inhibition greatly affected by porosity and ineffective surface materials.

According to observations, moisture content of concrete structures is very important which influences the performance of surface improvement materials when the combination of SPM and SCM is applied on mortar or concrete surface.

CONCLUSIONS

In this study, the experimental examinations were performed in order to evaluate the effectiveness of combination of SPM and SCM for concrete surface improvement. From the results, following conclusions were made.

1. Penetration depth of surface materials increased with increasing application amount of SPM and CRM.
2. Effect of neutralization resistance was confirmed with the use of CRM and with increasing application amount of combination of SPM and CRM.
3. Soluble chloride ion content, which is directly responsible for rebar corrosion, was reduced by using combination of SPM and CRM.
4. Increase in application amount of SPM and CRM decreased pore volume in concrete.
5. The moisture content of concrete just before applying the combination of materials is very important factor which influences the performance of the material.

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