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# Effect of Combining Silicate and Silane Type Surface Penetrants on Restraint to Deterioration in Concrete

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## ABSTRACT

Recently the surface penetrants are used to restraint the deterioration in concrete structures. Generally the silane type surface penetrants excel in water interception and the silicate type ones excel in resistance to carbonation. In this study, authors confirmed the effect of restraining deterioration on combining silane and silicate type one in order to utilize both good properties effectively. Two coating methods were used in this experiment. They are coating silicate type one after coating silane type one and vice versa. In the amount of water penetration test and the carbonation test the case of coating silane type one after coating silicate type one was the best result and the good effects were also confirmed by combining both surface penetrants.

**Keywords.** Surface penetrant, Silicate type, Silane type, Combination using, Deterioration

## INTRODUCTION

Many civil structures built in period of rapid economic growth, 1955 to 1973, in Japan and have been aging and their safety has been reduced by deterioration. The need for surface penetrants that are able to control the deterioration of concrete structures at a low cost has been increasing. It is thought that they are also needed as preventive maintenance method for new stuructures.

Several studies have previously been conducted on surface penetrants, so many of their effects and limitations have already been clarified (Mizutani, 2011, Sawada, 2010, Inoue, 2009, Takewaka, 2011).There are two principal types of surface penetrants, silane type and silicate type, and the following results have been obtained from prior researches: the silane type offers good water interception qualities, but it has low resistance to carbonation induced deterioration (Harakawa, 2010); in contrast, the silicate type has high resistance to carbonation induced deterioration, but offers poor water interception qualities (Harakawa, 2010); and finally, a mixed silicate and silane type penetrant, a combination type penetrant, were also examined, but detailed results have not yet been obtained (Harakawa, 2010). This combination type does exhibit better water interception than the silane type does, based on an examination using commercially available surface penetrants (Sawada, 2010). The ability of the combination type to control deterioration of concrete has not yet been made clear due to limited data.

The authors, therefore, examined the effect of the combination type on deterioration in concrete. Application of the combination type followed two patterns: applying a silicate type coating after a silane type coating (SK) and vice versa (KS). In this experiment, water cement ratio (W/C) of concrete was 60%. The coating ratios of the silicate type to the silane type were 20% to 80% for each standard coating quantity, 50% to 50% and 80% to 20% in KS specimens. In SK specimens, the coating ratios of the silane type to the silicate type were similar to KS specimens.

## OUTLINE OF EXPERIMENTS

**Surface penetrants used and the mixture proportions of concrete.** Tables 1 and 2 show the details of the surface penetrants used in this test. The meaning of abbreviations in Table 2 was explained by following example: SK28 shows coating silicate type on 80% for standard coating quantity of silicate type after coating silane type on 20% for standard coating quantity of silane type. Only a single kind of silicate type, sodium silicate and potassium silicate, and silane type, alkyl-alkoxysilane, were used, and the silane type only, silicate type only, and combination type cases were tested.

**Table 1. Surface penetrants used**

| Surface penetrant type | Major component | Concentration of major component (%) | Standard amount of application ($ml/m^2$) |
|---|---|---|---|
| silicate type | sodium silicate and potassium silicate | > 30 | 240 |
| silane type | alkyl-alkoxysilane | 98 - 100 | 300 |

**Table 2. Surface penetrants used and experimental conditions**

| Surface penetrant type | Amount of silicate type applied ($ml/m^2$) | Amount of silane type applied ($ml/m^2$) | Abbreviation |
|---|---|---|---|
| silicate type | 240 | 0 | silicate |
| silane type | 0 | 300 | silane |
| silane : silicate =2:8 | 60 | 192 | SK28 |
| silane : silicate =5:5 | 150 | 120 | SK55 |
| silane : silicate =8:2 | 240 | 48 | SK82 |
| silicate : silane =2:8 | 48 | 240 | KS28 |
| silicate : silane =5:5 | 120 | 150 | KS55 |
| silicate : silane =8:2 | 192 | 60 | KS82 |

*silane : silicate or silicate show the fraction for each standard amount of application

**Table 3. Mixture proportions of concrete**

| | G.max (mm) | Slump (cm) | W/C (%) | Air content (%) | s/a (%) | Unit content (kg/m$^3$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *W* | *C* | *S* | *G* | *Ad* |
| Concrete for SK | 20 | 10 | 60 | 5 | 46 | 167 | 278 | 824 | 1009 | 1.148 |
| Concrete for KS | | | | | 43 | | | 771 | 1065 | 0.835 |

The W/C of concrete was 60% and the target slump was 10±1cm and the target air content was 5.0±0.5%. Table 3 shows the mixture proportion of the concrete used in this test. The cement used was ordinary Portland cement, fine aggregate used was river sand, coarse aggregate used was tight sand typed crushed stone, chemical admixture used was lignosulphonate typed AE water reducing agent. The aggregate used was got from same area, but the physical properties were a little different from pickup periods and the mixture proportions of SK and KS were not same.

**Test specimen production.** The concrete specimens were cast and then demolded the next day. They were cured for 6 days in water curing and then cut to the appropriate size using a wet type cutter, cured for 28 days in constant temperature and humidity room. They were sealed at appropriate area with synthetic resin before 3 days completing atmospheric curing. The coating of surface penetrants was applied under the conditions outlined in Table 2 after completing atmospheric curing. For the silicate type, a brush was used to clean the area with water. After one hour, half the quantity of the coating was applied, and after one more hour, the area was cured by pouring water over it. The surface was then cured in the air for an additional hour. The remaining coating was then applied, and after one hour, the area was cured by pouring water over it, and then cured in the air for an additional hour. For the silane type, the area to be coated was cleaned using compressed air and then half the quantity of the coating was applied, followed by one hour of air curing. The remaining half of the surface penetrant was then applied, and the coated area was air cured for one hour.

For the combination type (KS), the silicate type coating was applied using the above mentioned method and the specimens were then air cured for 24 hours. The silane type coating was then applied. For the combination type (SK), the silane type coating was applied using the above mentioned method and after the 24 hours air curing silicate type coating was then applied. After the coating of surface penetrants, all type of the specimens was laid for 14 days at constant temperature and humidity room. This interval time of 24 hours was determined by preliminary test.

**The test method.** The depth of impregnation test, the amount of water penetration test, and resistance to carbonation test were carried out by following the testing methods outlined in the JSCE-K 571-2010 protocol. The tests were carried out using three specimens for each of the surface penetrant types, and the final value was determined by calculating the average value obtained from the three specimens.

**Depth of impregnation test.** The depth of impregnation for the silane type was measured using this test. The specimens were split into two parts and each part was then soaked in water for 1 minute. The water-proof depth was determined to be the depth of impregnation of the surface penetrants. The depth of impregnation was measured at three points: the center of the split surface and 25mm to each side of this point. These points were measured for both halves of the specimen, for a total of six points. The depth was measured in units of 0.1mm, and the average value was calculated for each specimen and then rounded to the first decimal place. The percentages of impregnation depth ($P_{id}$) were calculated with equation (1) from the results of impregnation depth test and they were rounded off to the integer.

$$P_{id}\,(\%) = \frac{\text{Impregnation depth of combination type specimen}}{\text{Impregnationdepth of silane type specimen}} \times 100 \tag{1}$$

**Amount of water penetration test.** Figure 1 shows the device used in the water penetration test. Based on 7.12 in JIS A 6909, the infundibulum and the measuring pipette were set on both the impregnated surface of the test specimens and the test surface of the normal test specimens so that there was no gap between them. The diameter of the infundibulum was 75mm and the minimum scale of the measuring pipette was 0.05ml. Distilled water was added to the apparatus, and it was kept at a constant temperature (20±2°C) and humidity (60±5%) for 7 days during the testing procedure. Seven days after the start of the test, the height of the water head ($W_{pi}$) was measured, and the amount of water penetration ($W_p$) was calculated using equation (2) which determined the difference between the height of the water head at 7 days and on the first day ($W_{p0}$).

$$W_p = W_{pi} - W_{p0} \tag{2}$$

The percentages of amount of water penetration ($P_{awp}$) were calculated with equation (3) from the results of impregnation depth test and they were rounded off to the integer.

$$P_{awp}\,(\%) = \frac{\text{Amount of water penetration in combination type specimens}}{\text{Amount of water penetration in silane type specimens}} \times 100 \tag{3}$$

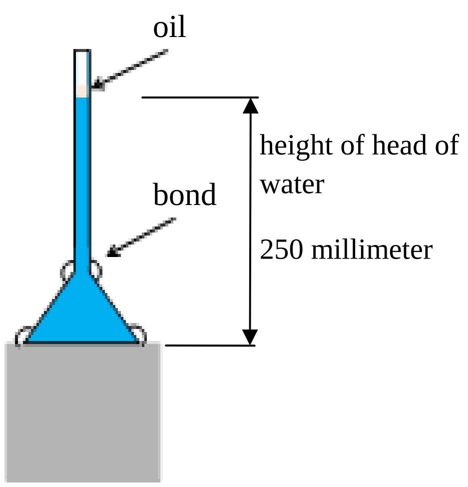


**Figure1. Equipment for testing amount of water penetration**

**Resistance to carbonation test.** The promoted carbonation test was carried out for 28 days following the protocol outlined in JIS A 1153. The test was carried out under constant conditions: a temperature of 20±2°C, a relative humidity of 60±5%, and a $CO_2$ gas concentration of 5±0.2%. The method used to measure the depth of carbonation was that outlined in JIS A 1152. The carbonation depth was measured in 0.1mm units at ten points of the impregnated and cleaved surface on both sides of the specimen using a caliper. The final carbonation depth value was determined by averaging the values of each of the carbonation test specimens.

The percentages of carbonation depth ($P_{cd}$) were calculated with equation (4) from the results of carbonation test and they were rounded off to the integer.

$$P_{cd}\,(\%) = \frac{\text{Carbonation depth in combination type specimens}}{\text{Carbonation depth in silicate type specimens}} \times 100 \qquad (4)$$

## RESULTS AND DISCUSSIONS

**Properties of concrete.** Table 4 shows the properties of the fresh concrete and the average compressive strength values at an age of 28 days. In any cases, the properties of concrete were almost same.

**Table 4. Properties of concrete used**

| | Concrete for SK | Concrete for KS |
|---|---|---|
| Slump（cm） | 9.0 | 9.0 |
| Air content（%） | 4.5 | 4.6 |
| Compressive strength for 7 days（$N/mm^2$） | 24.3 | 25.8 |
| Compressive strength for 28 days（$N/mm^2$） | 31.2 | 33.2 |
| Compressive strength for 91 days（$N/mm^2$） | 40.1 | 41.0 |

**The results of test for impregnation depth.** Figures 2 and 3 show the results of the impregnation depth test for surface penetrants. It was believed that the impregnation depth of silane type surface penetrant got lower as the amount of silane type was decreased like combination type. The above result was same as our prediction because the form of water-repellant layer was silane type's feature. In this test, the impregnation depth of silicate type was not measured.

Table 5 shows the percentages of the impregnation depth in KS and SK specimens. In this table, "silane" shows case of using silane type only and the values show the percentages of impregnation depth when it was supposed that the impregnation depth on using silane type only in series SK was 100%. The symbol "SK" shows data for coating silane type on no-coating specimens and "KS" shows data for coating silane type on silicate type coated specimens. From these results, when silane type was coated on concrete which the silicate type was coated, the impregnation depth of silane type was a little decreased in SK82 and KS28. It was believed that the silicate type does not affect to impregnation of silane type largely. When silicate type surface penetrant was coated on concrete, the silicate type reacted

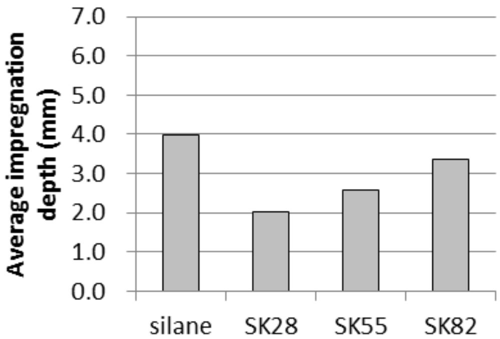


**Figure 2. Results of impregnation depth test (SK series)**

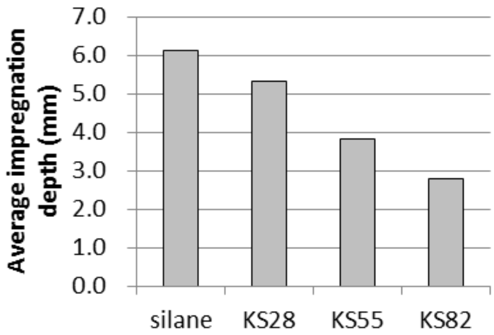


**Figure 3. Results of impregnation depth test (KS series)**

**Table 5. Percentages of impregnation depth**

| <SK series> | silane | SK28 | SK55 | SK82 |
|---|---|---|---|---|
| Percentages of impregnation depth (%) | 100 | 51 | 64 | 84 |
| <KS series> | silane | KS28 | KS55 | KS82 |
| Percentages of impregnation depth (%) | 153 (100) | 134 (88) | 96 (63) | 70 (46) |

to $Ca(OH)_2$ in concrete and the crystals of C-S-H are formed. The size of the crystals is about 1 to 10nm and this is similar to C-S-H crystals which are formed by hydration of cement. On the other hand, the size of alkyl-alkoxysilane of silane type is smaller than the size of C-S-Hcrystals. Therefore, it is believed that silane type penetrate to inside of concrete through the C-S-H crystals. From the results of SK28, SK55, KS55 and KS82, it is believed that large amount of silicate type coating prevent silane type from penetrating. The values inside parenthesis in Table 5 showed the ratio of impregnation depth when it was supposed that the impregnation depth on silane only in KS series was 100%. From this result, it was believed that the percentages of impregnation depth in KS series were nearly equal to that of SK series by the difference of coating amount of silane type.

**Amount of water penetration test.** Figures 4 and 5 show the result of the test for measuring the amount of water penetration. The amount of water penetration in silane type was smaller than those of normal (no coating) and silicate type like a past research (Inoue, 2009). This is considered because the water-repellent layer which is one of the features in silane type has formed in surface of concrete. The amounts of water penetration in SK82 and SK55 specimens were smaller than that of silane type only. This is considered because both silane type and silicate type has showed good effects.

Table 6 shows the result of comparison of SK series with KS series. The symbol "silane" in this table shows coating of silane type only. When the test result of silane type only in SK series was supposed 100%, the amounts of water penetration in SK and KS series were compared. From this result, it was believed that the amount of water penetration in combination type was decreased more than that of silane type which has high water interception. In comparison of SK series with KS series, the amount of water penetration in KS series which silicate type was coated ahead was lower than that of SK. It is considered that silicate type which was coated later was prevented from penetrating to concrete by

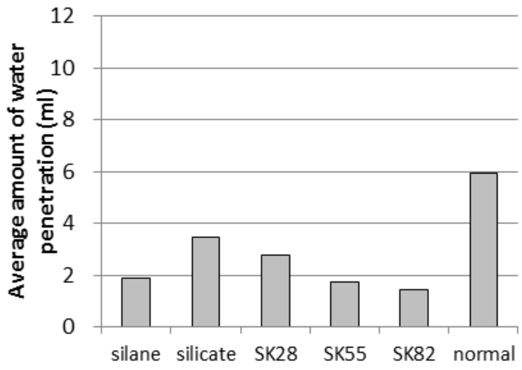


**Figure 4. The result of test for amount of water penetration (SK series)**

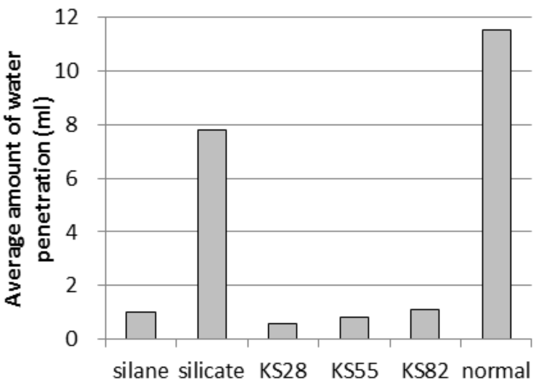


**Figure 5. The result of test for amount of water penetration (KS series)**

**Table 6. The percentages of amount of water penetration**

| <SK series> | silane | silicate | SK28 | SK55 | SK82 |
|---|---|---|---|---|---|
| Percentages of amount of water penetration (%) | 100 | 187 | 149 | 93 | 78 |
| <KS series> | silane | silicate | KS28 | KS55 | KS82 |
| Percentages of amount of water penetration (%) | 54 (100) | 419 (776) | 31 (57) | 45 (83) | 60 (111) |

water-repellent layer of silane type and the controlled effect of water penetration was reduced a little. The values inside parenthesis in Table 6 showed the percentage of amount of water penetration when it was supposed that the percentage on silane type only in KS series was 100%. From these results, it was believed that the amount of water penetration in KS series was more as the amount of silane type was less. But the tendency was not more clear than result in the percentage of impregnation depth.

**Test of resistance to carbonation.** Figure 6 shows the result of carbonation test in SK series. The silicate type was the best result in carbonation test of all cases. But SK28 showed the similar result of carbonation test to case of silicate type. It was clarified that all of SK specimens was able to control better than that of silane type. Figure 7 shows the result of

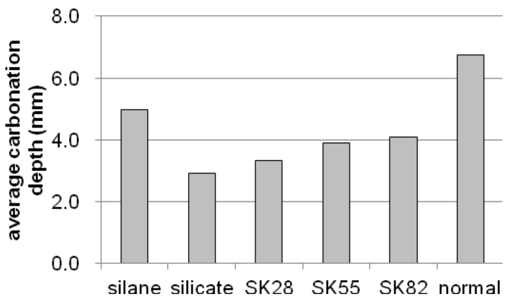


**Figure 6. The result of carbonation test (SK series)**

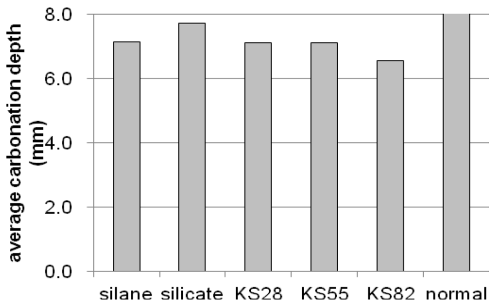


**Figure 7. The result of carbonation test (KS series)**

**Table 7. The percentages of carbonation depth**

| <SK series> | silane | silicate | SK28 | SK55 | SK82 |
|---|---|---|---|---|---|
| Percentages of carbonation depth (%) | 171 | 100 | 114 | 134 | 142 |
| <KS series> | silane | silicate | KS28 | KS55 | KS82 |
| Percentages of carbonation depth (%) | 189<br>(142) | 133<br>(100) | 149<br>(112) | 142<br>(107) | 142<br>(107) |

carbonation test in KS series. The specimens "silane", "silicate" and "normal" have a difference in Figures 6 and 7. This is because the concrete used in these test is not perfectly same by above mentioned reasons. It was believed that if the coating amount of silicate type was increased, there were no bad effects on carbonation

Table 7 shows the results on comparison of KS series with SK series. The symbol "silicate" shows case of using silicate type only and when the carbonation depth of silicate type in SK series is 100%, the percentage of carbonation depth in SK and KS series is shown in this table. It was believed that SK series were similar results to that of silicate type as the percentage of coating silicate type came to much. But the restraint effect of carbonation in SK series was not as high as that in KS series. This is considered because of water repellent layer by silane type like case of test for amount of water penetration. The values inside parenthesis in Table 7 showed the percentage of carbonation depth when it was supposed that the percentage on silicate only in KS series was 100%. From these results, it was believed that the percentage of carbonation depth was lower as the amount of silicate type was much. From the comparison of percentage of carbonation depth in parenthesis with that of SK series, it was believed that the restraint effect of KS series was higher than that of SK series.

**Considerations.** From these test results, it was believed that the effect of water interception by combination of silicate type and silane type was higher than those of using silicate type only or silane type only. Particularly KS series had higher property of water interception. On the other hands, the silicate type only showed the best results for resistance to carbonation. KS series showed better results for carbonation than SK series. From the consideration of properties of water interception and resistance to carbonation totally, it was believed that the combination type like KS28 was the best because KS28 showed the best results for property of water interception and similar results to resistance to carbonation.

In these tests, the restraint effect to deterioration in KS series was higher than that of SK series. This was because silane type was coated before coating of silicate type and the water repellent layer was formed in the surface of concrete, impregnation of silicate type later was prevented a little. But in these tests the grades of impregnation of silicate type could be confirmed, it was necessary to confirm to understand them in the future.

## CONCLUSIONS

The combination type, KS28, showed the best results for controlling of water penetration.

The silicate type only was the best results for controlling of carbonation, combination type in KS series showed similar results to that in silicate type only.

In these tests, the restraint effects to deterioration by combination of a kind of silicate type and a kind of silane type were researched. From these results, it was believed that the restraint effects to deterioration by combination type were higher than those of silicate type only or silane type only. These effects may be different due to kinds or combinations of surface penetrants, it was clarified that the best percentage of combination type was KS28 in these tests.

## ACKNOWLEDGMENT

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