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Effect of a Hydrophobic Agent as Repair Material for Concrete Structures

Produit hydrophobe pour la réparation de structures en béton

Wasserabstossendes Mittel zur Reparatur von Betontragwerken

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SUMMARY

Recently, many kinds of surface treatments have been applied to repair concrete structures deteriorated due to alkali-silica reaction and/or reinforcement corrosion. Among those materials used for surface treatments, silane is a typical hydrophobic impregnant to control water existing in concrete. However, since silane includes many kinds of branches which have various properties according to their molecular structures, it is necessary to identify which one has the best hydrophobic property. In this study, the effect of the molecular size, the type and the number of alkoxyl groups of silane on the hydrophobicity of concrete were investigated.

RÉSUMÉ

De nombreuses méthodes de traitement de surface ont été utilisées tout récemment pour réparer les dommages occasionnés au béton par une réaction de silicate alcalin et/ou par une corrosion des armatures. Parmi ceux-ci, le silan est un produit d'imprégnation typiquement hydrophobe, destiné à contrôler la teneur en eau du béton. Il existe toutefois de nombreuses combinaisons de ce produit ayant des propriétés différentes, en fonction de la structure moléculaire, ce qui implique de devoir trouver celle qui possède le meil-leur pouvoir hydrophobe. Les auteurs présentent ici une étude de la taille des molécules, du type et du nombre de groupes d'alcoxydes contenus dans le silan et qui ont une in-fluence sur le caractère hydrophobe du béton.

ZUSAMMENFASSUNG

In jüngster Zeit wurden vielerlei Oberflächenbehandlungen zur Reparatur von Betonschäden infolge Alkali-Silikat-Reaktion oder Bewehrungskorrosion angewendet. Von diesen ist Silan ein typisches hydrophobes Imprägnierungsmittel, um den Wassergehalt im Beton zu begrenzen. Allerdings gibt es viele Spielarten mit unterschiedlichen Eigenschaften, je nach Molekularstruktur, so dass jene mit der besten Wasserabstossung herausgefunden werden muss. Berichtet wird über eine Studie zum Einfluss der Molekülgrösse, der Art und Anzahl von Alkoxylgruppen im Silane auf die Hydrophobität von Beton.

1. Introduction

A number of cases of premature deterioration of concrete structures caused by alkali-silica reaction and/or chloride induced corrosion of reinforcing steel have been reported recently. It is well known that water plays one of the most important roles in these deterioration mechanism. Taking this into consideration, in order to avoid the deterioration, many kinds of surface treatments which can control water content in concrete are applied to concrete structures. Such surface treatments can be classified into two categories from the viewpoint of how to control the water in concrete. One includes the treatments which permit no water to ingress into concrete, and no water to get out from concrete in the same way. The other includes the hydrophobic treatments which permit liquid phase water to penetrate into concrete rather little, but can make vapor phase water in concrete get out on the contrary. Since the former systems may cause deterioration by the water fixed in concrete, the latter have got focused as superior methods [1].

In the latter systems, silanes are commonly used as typical hydrophobic impregnants. This paper describes the hydrophobic surface treatments for concrete using some types of silanes adopted in repair works of concrete structures. Silanes are silicone-based products of low molecular weight and used as the alkylalkoxylsilanes [2]. When a silane is applied to concrete surface, a series of chemical reactions between the silane and the silicate structure of concrete occurs in two steps, which are hydrolysis and condensation. During the hydrolysis, the moisture provided from concrete produces unstable silanol molecules. During the condensation, the unstable silanol molecules shake hands with available hydroxyl groups in the silicate structure and some crosslinkings occur. In this way, the silane-treated concrete becomes water repellent [3].

2. Outline of experiment

2.1 Molecular structures of silanes

By changing the kind and number of the alkyl and alkoxyl groups of silanes,nine kinds of silanes indicated in Table 1 were prepared. These were used as 1mol solutions of isopropyl alcohol.

Name	Molecular formula (alkyl) (alkoxyl)	Molecular weight	Note
dimethyldimethoxy silane	$(CH_3)_2Si(OCH_3)_2$	120	two alkoxyls
methyltrimethoxy silane	$CH_3Si(OCH_3)_3$	136	alkoxyl is methoxy.
ethyltrimethoxy silane	$C_2H_5Si(OCH_3)_3$	150	
iso-butyltrimethoxy silane	$C_4H_9Si(OCH_3)_3$	178	
n-octyltrimethoxy silane	$C_8H_{17}Si(OCH_3)_3$	234	
n-deciletrimethoxy silane	$C_{10}H_{21}Si(OCH_3)_3$	262	
n-octadeciletrimethoxy silane	$C_{18}H_{37}Si(OCH_3)_3$	374	
methyltriethoxy silane	$CH_3Si(C_2H_5)_3$	178	alkoxyl is ethoxy.
n-octadeciletriethoxy silane	$C_{18}H_{37}Si(C_2H_5)_3$	416	

Table 1 Silanes and their molecular structures

2.2 Preliminary experiment

Preliminary experiment was conducted to select from the nine kinds of silane, those used in the main experiment. The specimens were small concrete prisms (40x40x160mm) with non-reactive aggregate. After being cured in water for three months, they were dried in air for a week and then impregnated with the silanes. After two days from the impregnation, the specimens were placed under four different conditions - indoors, underwater, in the dry and wet chamber (20℃, 60%RH, 12Hr ⇔ 40℃ 100%RH, 12Hr), or outdoors. The hydrophobic performance of each silane under each condition was evaluated from weight changes of the specimens.

2.3 Main experiment

The specimens were concrete prisms (100x100x400mm). Table 2 shows the types of concrete, silanes, and the conditions. For corrosion series, three deformed bars (300mm) were embedded in the specimens. After being cured at 20℃, 80%RH for two weeks, each specimen got impregnated with one of the four silanes selected in the previous test, subsequently were placed in each condition. During this experiment, weight changes, strain and halfcell potential were measured.

concrete	non-reactive without chloride, non-reactive with chloride reactive without chloride, reactive with chloride
silane	non-treatment, 234,262,374,416 (molecular weight)
condition	outdoors, dry and wet chamber, partially immersing in chloride solution (NaCl: 3.13%)

Table 2 Factors for main experiment

3. Results and Discussions

3.1 Preliminary experiment

From the viewpoint of controlling the ingress of water into concrete from outside, the feature to make no water penetrate into concrete is needed. On the contrary, from the viewpoint of making water in concrete get out, the ability to permit water to move out of concrete is expected. The former is mainly related with liquid phase water, and the latter with vapor phase water. As the water in concrete has a great influence both on its expansion due to alkali silica reaction and on the rate of reinforcement corrosion, surface treatments are expected to have the ability not only to permit little liquid phase water to penetrate into concrete but also to permit a lot of vapor phase water in concrete to get out. As the weight changes of indoor specimens and those of underwater specimens can be regarded as indexes of "water vapor permeability" and "water liquid permeability" respectively, a larger ratio of "water vapor permeability/water liquid permeability" corresponds to better hydrophobic performance.

3.1.1 Water vapor permeability

Fig.1 shows the relationship between molecular weight and water vapor permeability. After 9 days of exposure, the silanes of smaller molecular weight in methoxy series had the larger water vapor permeability. The same tendency was observed in ethoxy series as well. The tendency was still observed after 30 days of exposure, although the influence of molecular weight on the water vapor permeability was reduced to some extent. These results indicate that the water vapor permeability of the silanes of smaller molecular weight was generally larger than that of larger ones during the above period.

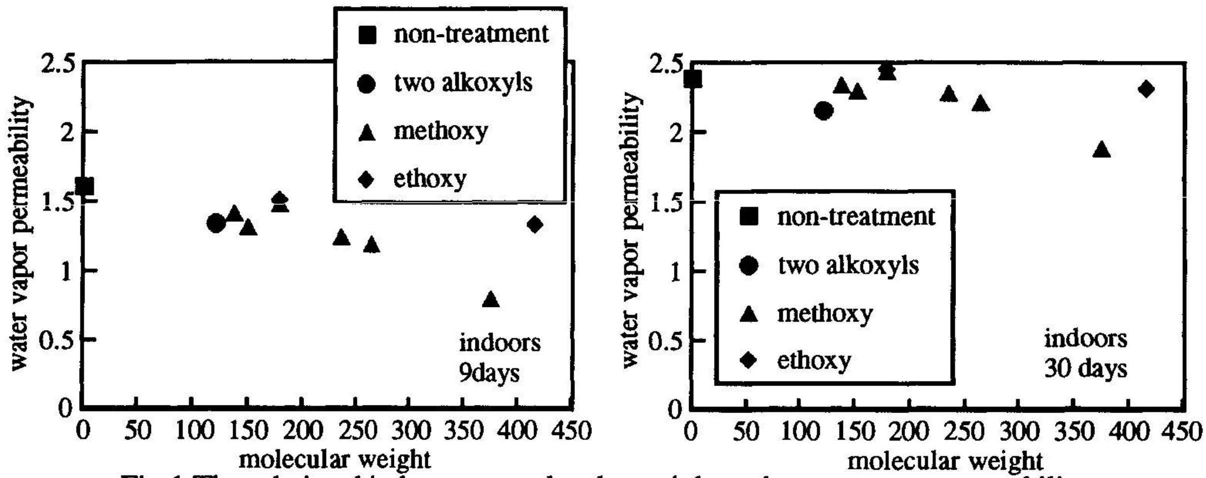

Fig.1 The relationship between molecular weight and water vapor permeability

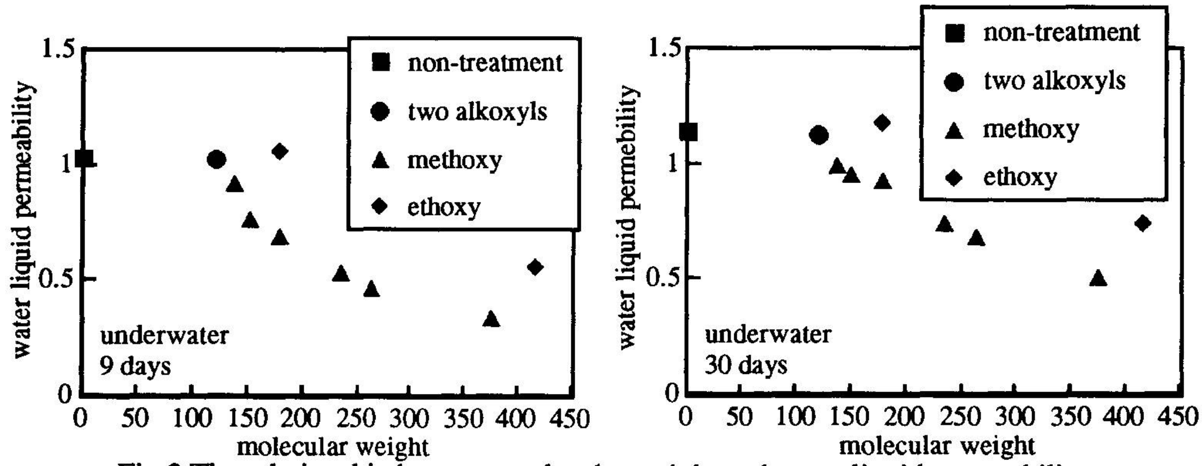

Fig.2 The relationship between molecular weight and water liquid permeability

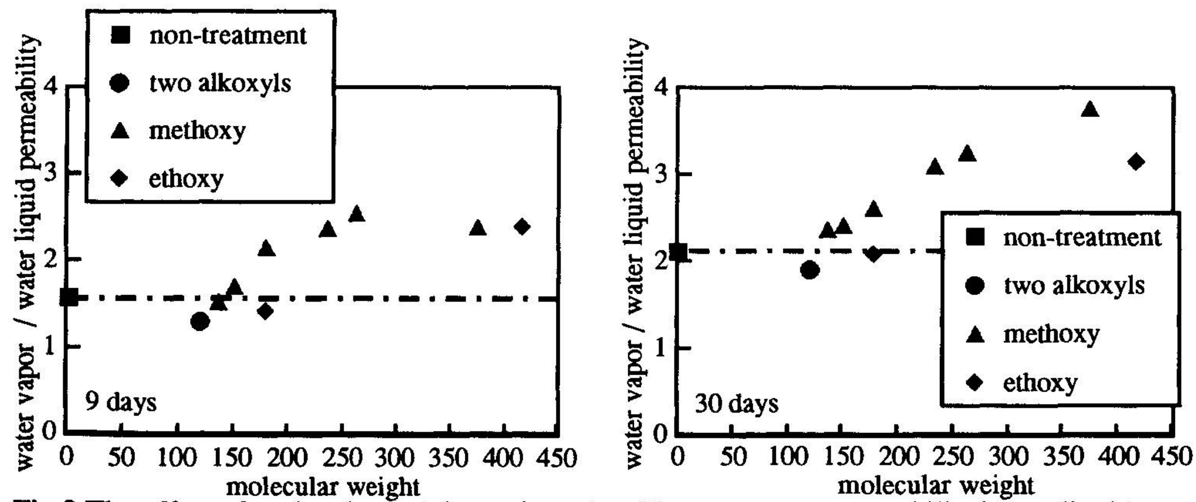

Fig.3 The effect of molecular weight on the ratio of "water vapor permeability/water liquid permeability

3.1.2 Water liquid permeability

Fig.2 shows the relationship between molecular weight and water liquid permeability. In methoxy series, the silanes of larger molecular weight showed the lower water liquid permeability. Since the size of the hydrophilic alkoxyls were the same, this might be due to longer hydrophobic alkyls corresponding to larger molecular weight. The same tendency was observed in ethoxy series as well -

the silanes of larger molecular weight had better resistance against penetration of water.

3.1.3 "Water vapor permeability / Water liquid permeability"

Fig.3 shows the effect of molecular weight on the ratio of "water vapor permeability / water liquid permeability". After 9 days of exposure, while 136, 150 and 178(MTES) showed smaller ratios as compared with that of the non-treated specimen, 262, 234, 374 and 416 of larger molecular weight similarly had good hydrophobicity. Similar results were obtained after 30 days of exposure, that is, when the larger molecular weight resulted in the larger ratio. The silanes which showed large ratio also indicated good hydrophobicity under dry and wet chamber and outdoors conditions. Considering that the actual concrete structures are exposed to dry and wet condition and the relatively small size of the specimens were used in the preliminary experiment, the silanes used in the main experiment was selected mainly on the basis of the results of hydrophobicity in 9 days of exposure. For this reason, the four types of silanes of molecular weight 234, 262, 374 and 416 were selected. Among them, 262 was regarded to have the best hydrophobic property in this series.

3.2 Main experiment

3.2.1 Weight changes

Under all conditions, the weight changes of all specimens impregnated with the silanes were smaller than that of the non-treated specimens. This indicates that the silanes could also control the water content of the specimens used in main experiment. Viewed in terms of weight changes, the silanes proved to be highly effective, especially under the condition of partially immersing in chloride solution.

3.2.2 Effect on expansion caused by alkali-silica reaction

Fig.4 shows the strain under the dry and wet condition. It is observed that non-treated specimens expanded significantly due to the influence of reactive aggregate and chloride. On the other hand, the specimens impregnated with the silanes expanded much less than non-treated specimens. The result indicates that they controlled the water content in the specimens and were quite effective against alkali-silica expansion. However, since the strains of treated specimens were too much larger than those of the specimens without reactive aggregate, it should be noted that unless concrete is mixed properly, the silanes would fail to restrain concrete from excessive expanding in a long term.

3.2.3 Effect on reinforcement corrosion

Fig.5 shows some results of the halfcell potential obtained from the non-reactive specimens in the condition of partially immersing in chloride solution. While the

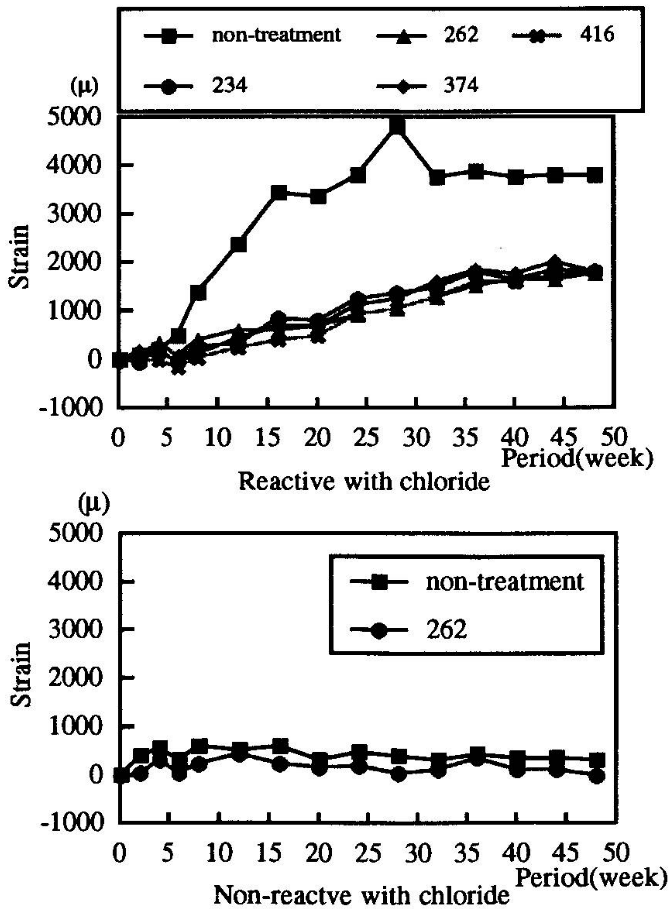

Fig.4 Strain

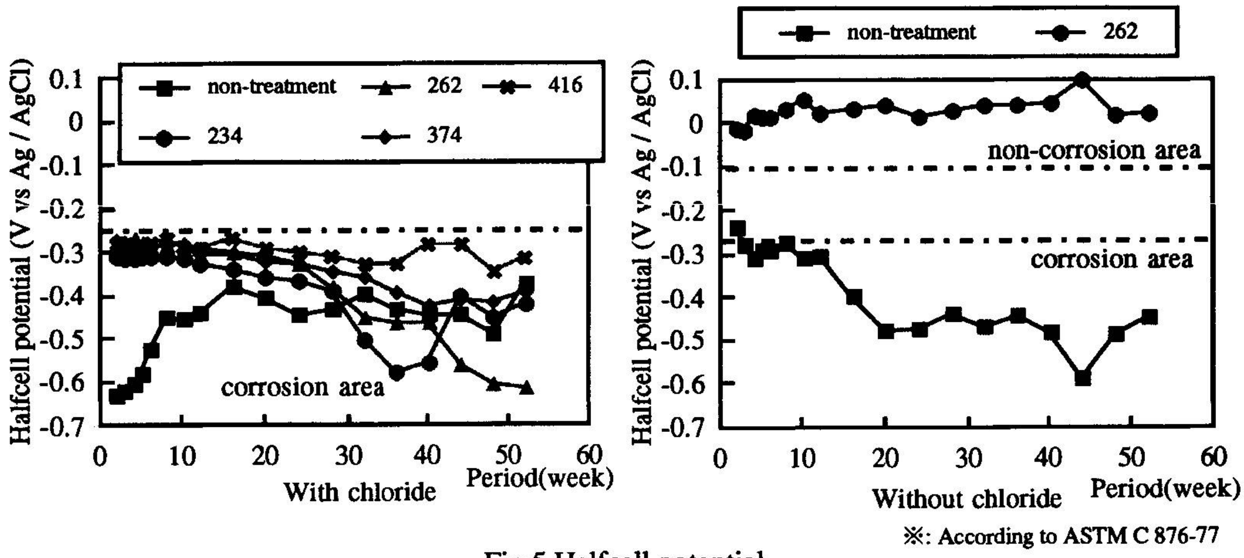

Fig.5 Halfcell potential

halfcell potential of the non-treated specimen without chloride was in the corrosion area, that of the specimen impregnated with 262 was still in the non-corrosion area. This indicates that the silane worked effectively also against corrosion of reinforcement caused by the chloride solution. However,when concrete included much chloride, although the halfcell potential of the impregnated specimens were less negative than that of non-treated specimens in a short term, they gradually became negative with the time passing until some of them were more negative than that of non-treated specimens.

4. Conclusion

The main results obtained in this study are summarized as follows.

1. The silanes of small molecular weight made the large amount of water get out. On the other hand, the silanes of large molecular weight which have long alkyl groups had better resistance against the ingress of water. Among the silanes used in this experimental study, the silane of molecular weight 262 showed the best hydrophobic performance.
2. The silanes worked effectively against the expansion of concrete caused by alkali-silica reaction and the reinforcement corrosion. That is, by impregnating the silanes to concrete, the expansion and the halfcell potential were reduced or even restrained. However, if concrete included an excessive amount of reactive potential and/or chloride, it was difficult to restrain deterioration of concrete in a long term.

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