K-4 Guidelines on silicate-based surface penetrants used for concrete structures to prevent penetration of harmful agents

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ABSTRACT: Surface penetrant is one of the materials used to treat concrete surface. When applied to concrete surface, surface penetrant penetrates into the concrete and improves the properties of the affected regions in a number of specific ways, such as densifying, strengthening, enhancing the alkalinity of the affected regions, and enhancing water repellency, thus improving the quality of the surface layer composition and contributing to greater durability of the concrete structure. At present, there are two most commonly used types of the penetrant, one is silane-based surface penetrant, which impede the penetration of water by investing the water repellency on the concrete surface, and the other is silicate-based one, which serve to densify the concrete surface to prevent harmful substances coming from environment. Among the advantages common to all types of surface penetrants, the following points may be listed:

1. *Colorless and transparent, ensuring no degradation of the external appearance of the concrete surface.*
2. *Easiness to apply, and to be able to apply quickly with little effort compared to other techniques, such as coating methods or lining methods.*
3. *Environmentally friendly materials of which application generates little industrial waste, and they do not employ organic solvents or other harmful materials.*

In the presentation, among these impregnated materials, outlines of silicate-based penetrants will be mainly described with explaining their performance, points to be considered in terms of use, quality confirmation test and practical examples of construction.

KEY-WORDS: Surface penetrant, silicate-based penetrant, surface impregnation, maintenance of concrete structures, repair method, durability of the concrete structure

FEATURE OF SURFACE PENETRANT

Surface penetrant is one of materials used to treat concrete surface. When applied to a concrete surface, it penetrates into the interior of the concrete and improves the properties of the affected regions in a number of specific ways, such as including densifying, strengthening, enhancing the alkalinity of the affected regions, and enhancing water repellency, thus improving the quality of the surface layer composition and contributing to greater durability of the concrete structure. At present, there are two most commonly used types of the penetrant, such as one is silane-based surface penetrants, which increase the water resistance of the concrete surface by impeding the penetration of water, and another is silicate-based ones, which serve to densify the concrete surface to prevent harmful substances from entering the material.

Among the advantages common to all types of surface penetrants, the following points may be listed: (1) colorless and transparent, ensuring no degradation of the external appearance of the concrete surface. (2) easiness to apply, and to be able to apply quickly with little effort compared to other techniques, such as coating methods or lining methods. (3) environmentally friendly materials of which application generates little industrial waste, and they do not employ organic solvents or other harmful materials.

BRIEF HISTORY OF THE DEVELOPMENT OF THIS TECHNOLOGY

As early as the 1920s, surface penetrants were used as waterproofing materials for buildings in various countries around the world, including northern Europe, North America, and Australia. In Japan, surface penetrants began to be used in the 1970s primarily as architectural waterproofing materials. From the latter half of 1990s, they were being investigated as materials to improve the durability of concrete structures in the civil-engineering domain. However, until that time, there had been little specific or objective assessment of surface penetrants. And, they

were used only because they were simple to apply and economical. For this reason, in 2001, the Subcommittee on Concrete Surface Coatings and Surface Improvement Technologies was established in the Japan Society of Civil Engineers (JSCE) to take up the task of aggregating technical data on surface penetrants. Furthermore, in 2005, "Recommendation for Concrete Repair and Surface Protection of Concrete Structures (Proposal)" was formulated by the JSCE's Subcommittee on Surface Protection Methods[1]. Also in the recommendation, collected data in the committee's activities were subsequently summarized in the "Manual for Surface Penetrant Materials" in which contained a document relating design and implementation guideline.

At present, the surface penetrants used for concrete structures may be broadly classified into two groups: silane-based and silicate-based materials. However, at the time that the aforementioned guideline proposal was formulated, there was not yet much survey data on silicate-based surface penetrants. Thus, the proposal inevitably focused on silane-based materials, primarily discussing their performance, their range of applicability, and methods for testing and assessing their performance. To remedy this shortcoming, in 2009 the JSCE convened a new Subcommittee on "Design and Application of Silicate-Based Surface Penetrants", and in 2012, a document titled "Design and Construction Methods for Concrete Structures using Silicate-type Surface Penetrants (Proposal)" was formulated[2].

THE MECHANISMS UNDERLYING THIS TECHNOLOGY

(1) Silicate-based surface penetrants

The primary ingredients in silicate-based surface penetrants are silicates such as lithium silicate, sodium silicate, and potassium silicate; these may be used individually, or blended. The mechanisms by which silicate-based surface penetrants improve the quality of surface layers may be classified as follows;

a) *Reactive silicate-based surface penetrants:* In this case, silicates that penetrate into the interior of concrete react with calcium hydrates [$Ca(OH)_2$]—which are produced in copious numbers by the hydration of cement—to form calcium silicate hydrate (CSH gel). This process, together with the hydrates formed by the cement hydration reaction, serves to densify the penetrated regions of the concrete.

b) *Solidifying silicate-based surface penetrants*: In this case, penetrants that migrate into the interior of concrete react with $Ca(OH)_2$ immediately after penetration to form CSH gel. However, the penetrants themselves subsequently dry and solidify in the concrete, forming an insoluble solid that fills in pores and gaps in the concrete, thus densifying the material.

The solidifying type of surface penetrant forms insoluble crystal under dry condition, which can fill pores in concrete, then the concrete surface is improved. The concrete surface impregnated with the penetrant, therefore, should be dry-cured after application. In contrast, the reactive type of penetrant dissolves in water and reacts with the calcium hydroxide in concrete. For this reason, wet curing of the concrete surface is necessary. They mean that the solidifying type and reactive one must be cured under opposite conditions, and a selection of the correct curing method is one of the most important requirements for reliable application of the penetrants.

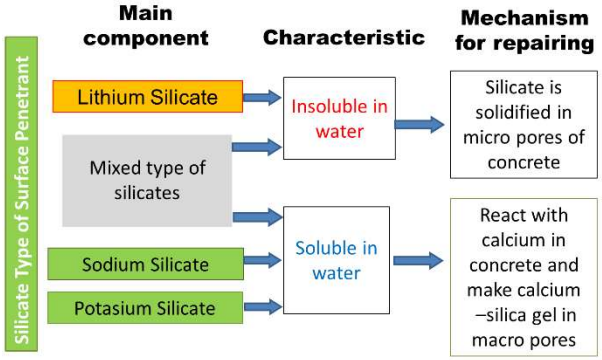


Fig.1. Relationship between principal components and surface modification mechanism

(2) Silane-based surface penetrants

Silane-based surface penetrants consist of a primary ingredient—an alkylalkoxysilane monomer, an oligomer, or some mixture of these—diluted by water or an organic solvent. Applying such a material to a concrete surface causes it to penetrate into the interior of the concrete, where it chemically binds with hydroxyl groups (OH^-) in the

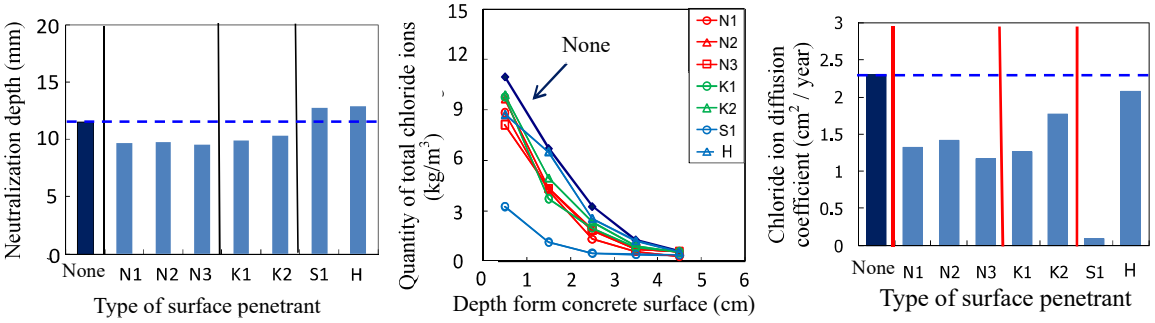
concrete, forming a water-repellent layer that extends to a depth of a few millimeters below the surface. However, the water-repellent nature of this layer arises through the creation of hydrophobic layers in the inner walls of pores in the concrete, and the pores themselves are not filled in. For this reason, the motion of gases such as air or water vapor through the concrete is not obstructed; hence, a characteristic of silane-based surface penetrants is that they exhibit only the property of preventing water absorption.

EXAMPLES OF PRACTICAL APPLICATION

As examples of successful applications of surface penetrants to concrete structures in the civil-engineering site;

(1) Cases in which surface penetrants were applied as preventative and maintaining materials to structures for which deterioration due to salt damage, neutralization, freezing, or alkali-aggregate reactions was a concern.

(2) Cases in which surface penetrants were applied as under-coatings for repaired portions or over-coatings to ensure the performance of the cross-sectional repairs portions.



(a) Accelerated neutralization test results (b) Chloride penetration test results

Fig.2. Effects of surface penetrants on reducing concrete neutralization and salt penetration[2].

(N1, N2, N3: sodium silicate; K1,K2: Blend of sodium silicate and potassium silicate; S1: silane; H: blend of silane and sodium silicate)

Fig. 1 shows an example of the effect of surface penetrants. Using silane-based surface penetrants also improves the water resistance of concrete, and offers the additional benefit of ensuring the easy motion of gases throughout the concrete, thus allowing moisture within the concrete to be released in the form of water vapor. However, the drawback of this approach is that gases are able to enter the concrete easily from the outside, ensuring that the treatment does not necessarily offer good protection against neutralization or other phenomena.On the other hand, there are a number of cautions—common to all applications of surface penetrants—to keep in mind, including the following:

(1) Although the most desirable effect is to prevent degradation-causing agents from entering the material, it is difficult to block these agents entirely.

(2) Because the external appearance of the concrete is unchanged by the application of the materials, it is not possible to determine by visual inspection whether or not a concrete surface has been treated.

(3) The depth of penetration ranges from a few millimeters to over 10 millimeters. The deeper the penetration, the greater the impact of the treatment in preventing deterioration. However, this depth depends on factors such as the water content of the concrete, the status of neutralization, and the type of cement used.

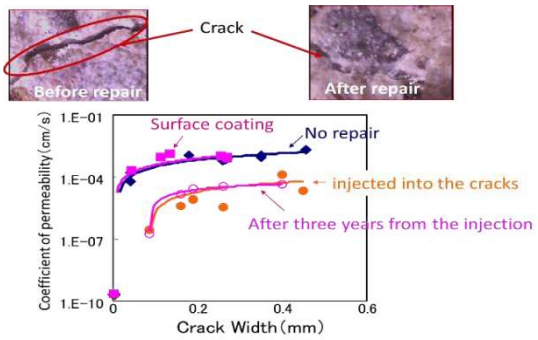


Fig.3. Water permeability at crack portion

Additionally, in Fig. 2, improvement effect of impermeability due to injecting silicate-based surface penetrants

into regionally exhibiting cracks has been clearly confirmed to improve water penetration.

ESTABLISHMENT OF GUIDLINE FOR DESIGN AND APPLICATION OF PENETRANTS ON CONCRETE SURFACE, AND TEST METHODS FOR THE PERFORMANCE EVALUATION

When using silicate-based surface penetrants as the repair method on concrete surface, the following advantages will be considered:

(1) Can be used relatively easily compared with other materials and construction method.
(2) Excellent in cost performance.

Therefore, for considering more effective usage of the concrete surface penetrants, in July 2012, Japan Society of Civil Engineer published a guideline, titled "Guideline on Design and Application Methods of Silicate-based Surface Penetrants used for Concrete Structures (Fig.3)" which seems to be a first guideline for "silicate-based surface penetrant" in the world.

Guideline on Design and Application Methods of Silicate-based Surface Penetrants Method for Concrete Structures

- Chapter 1: General
- Chapter 2 : Types of Silicate-based Surface Penetrants
- Chapter 3 : Quality of Silicate-based Surface Penetrants
- Chapter 4 : Design for durability of concrete using Silicate-based Surface Penetrants
- Chapter 5 : Implementation Method
- Chapter 6 : Quality Inspection after Implementation
- Chapter 7 : Maintenance

Fig.4. JSCE Guideline for silicate-based surface penetrants

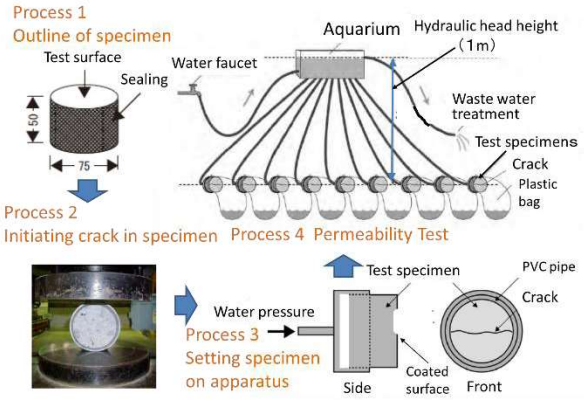


Fig.5. JSCE test methods for qualifying the silicate-type surface penetrants for water permeability from concrete crack

Table 1. JSCE test methods for qualifying the silicate-type surface penetrants for effectively using in concrete structures

Title of Testing method
1. Chemical Reactivity
2. Residual Solid Weight after Drying-up in Penetrant
3. Judgment on Types of Surface Penetrant
4. Judgment on Outward Appearance
5. Penetration depth of penetrant in Concrete
6. Water Permeability
7. Water Absorption
8. Resistivity against Carbonation
9. Resistivity against Scouring
10. Blockage Property at Crack Portion
11. Water Permeability under Pressurization

Additionally, for evaluating characteristics relating the repair degree of penetrant directly on concrete surface, eleven test methods, which can check very important performance quantitatively each other, should be also placed on the guideline (see Table 1). Fig. 4 shows one of the newly developed test methods for water permeability at crack portion, and it can be very effective for evaluating a blockage performance at crack portion by penetrant, which is one of the most important characters for the penetrant.

CONCLUSIVE REMARKS

1. Silicate-based surface-penetrants, as already mentioned, can be used relatively easer comparing with other materials or methods for repair/ rehabilitation of concrete structures. However, to make better use of the performance possessed by the penetrants, it is necessary for engineers, who plan to use the material or carry out the use it, need to have higher knowledge and technical ability.

2. In order to bring out the performance of silicate-based surface-penetrants more effectively, the engineer, who plans to use this material or just carries out its use, also needs to have higher knowledge and skill for using the material.

3. Excellent in cost performance. However, in order that surface penetrant material is more effectively utilized for the quality improvement of concrete, need to establish the followings:
    1. Quantification of improvement mechanism of the material to concrete quality
    2. Establishment of quality criteria
    3. Standardizing test methods for checking quality of material, quantitatively.

On the other hand, unfortunately, world-widely, there is not any gridlines and specification for using the penetrants on the concrete structures, and the testing method to evaluate the material quality and performance. However, when the surface penetrants are used effectively in concrete structures, we had to know these performances and its limit, at least before using. And for evaluating such conditions of the material, a guideline for design and construction or application for these materials on the concrete structure shall be developed.

Furthermore, testing methods should be prepared world widely to evaluating performances not only for the materials its self but also the concrete repaired by them.

REFERENCES

[1] Japan Society of Civil Engineers (JSCE): Recommendation for Concrete Repair and Surface Protection of Concrete Structures, Concrete Library 119, 2005.
[2] Japan Society of Civil Engineers (JSCE): Recommendation for Design and Construction Methods for Concrete Structures using Silicate-type Surface Penetrants, Concrete Library 137, 2013.