SILANE SEALERS/ HYDROPHOBIC IMPREGNATION— THE EUROPEAN PERSPECTIVE

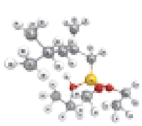
BY AAMER SYED AND MICHEL DONADIO

Hydrophobic sealers are used to prevent water and water-soluble deleterious materials from penetrating mineral substrates. These hydrophobic impregnation treatments change the surface tension of the mineral substrates, including concrete, render, and brickwork.

This change in surface tension produces a water-repellent surface to keep water and aggressive water-soluble salts, such as chlorides and sulfates, out of the substrate.

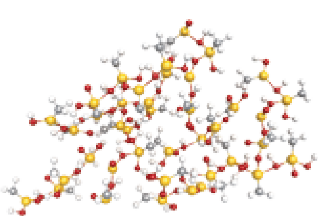
1. THE DIFFERENT TECHNOLOGIES

1.1 SILANES



Different types of molecules are available in the market. Silanes, typically triethoxy (2,4,4-trimethylpentyl) silane, are very small molecules (approximately 1×10^{-9} to 5×10^{-9} ft) (approximately 0.4 to 1.5 nm), are highly alkali-resistant, show high volatility, and are well-suited for concrete substrates. They have the ability to migrate deep into the substrate, but due to their high volatility, a high concentration of material is required. Various types of formulations exist in the market, from almost pure silane (99% active content) to diluted water-based emulsions (>20% active content) and will differ in their uses and performances.

1.2 SILOXANES



In layman's terms, a siloxane could also be called a "polysilane," as they are similar in nature but are much more complex molecules. Siloxanes, like silanes, are also very small (approximately 1×10^{-8} to 9.8×10^{-8} ft) (approximately 3 to 30 nm) but cannot migrate as deep into the substrate due to their complexity and shape. They are less volatile, so a lower concentration can be afforded. Like the silanes, they are also alkali-resistant. They can be used in concrete, but due to their lower penetration, they are mainly used in more porous mineral substrates, such as brick and natural and artificial stone.

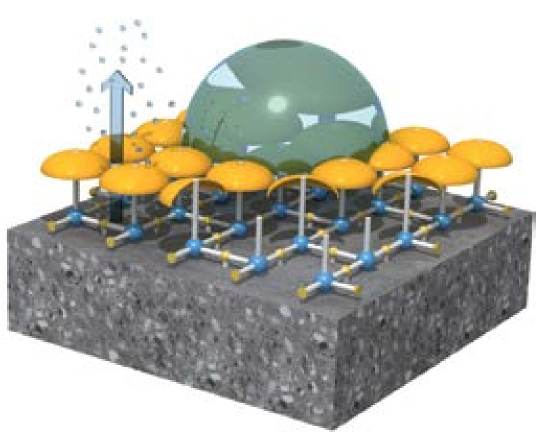


Fig. 1: Schematic 3-D view of silicone resin network preventing liquid water from penetrating while allowing moisture to escape

Maximum active content generally does not exceed 10 to 15%—any higher than that and there is some risk of surface darkening as the molecule will "sit" at the surface. Solvent or water carriers are commonly used.

1.3 SILICONATES

These are the smallest molecules at 9.8×10^{-10} to 2×10^{-9} ft (0.3 to 0.6 nm) and the simplest of the three chemicals. However, due to their polarity, they cannot penetrate as well into the mineral substrates.

Additionally, siliconates are not stable under alkali conditions; therefore, they are mainly used in non-alkaline mineral substrates, such as bricks and natural stones.

2. STANDARDS

2.1 EN 1504-2

In Europe, the use of hydrophobic sealers or hydrophobic impregnation is regulated via the global standard for repair and protection of concrete substrate, EN 1504. Hydrophobic sealers shall comply with the relevant criteria of Part 2.

While Items 1 through 3 in Table 1 relate to performance criteria the products must comply with, Items 4 and 5 classify the products in different levels.

Products complying with Class I of the drying rate test have little to no incidence to the vapor transmission ability of the substrate. Class I is preferred when it is desired to have some drying effects (for example, to fight against the alkali-silica reaction or to reduce the corrosion rate of the reinforced bars).

Products complying with Class II of the penetration depth have the ability to penetrate dense substrates, although works done by Johansson et al.[1]

and Wittmann et al.[2] have shown hydrophobic impregnation hardly penetrate in very high-performance concrete (water-cement ratio [w/c] ≤ 0.35).

Generally, only high performing products (silane with a high concentration of solid content) can be classified as Class II for the penetration depth.

Lower performing products (for example, diluted silane, either in water or solvent, or siloxane material), although compliant with EN 1504-2, cannot achieve this classification.

EN 1504-2 does not require a specific test for chloride penetration to be performed, so this is left to the national regulations. It is also said that if a product demonstrates a water capillary uptake lower than 0.002 lb/ft^2.h$^{0.5}$ (0.01 kg/m^2.h$^{0.5}$), it is deemed that diffusion of chlorides is not to be expected.

2.2 AMERICAN STANDARDS

In the United States, hydrophobic sealers shall comply with various standards according to the relevant department of transportation (DOT). The most commonly used test methods are from NCHRP (National Cooperative Highway Research Program) Series II and IV. Although these tests are only for comparative study, they are often used as the basis for DOTs specifications.

The Series II program requires hydrophobic sealers to be tested for water capillary uptake, chloride penetration, and water vapor transmission, and for the Series IV program, accelerated weathering for the Southern and Northern climate is taken into consideration.

There is a test method to measure penetration depth of the hydrophobic sealers applied on the structure (OHD L-34 and 35) but only a limited number of DOTs have included penetration depth as part of their specifications. The DOT from Oklahoma and South Carolina require 0.16 in. (approximately 4 mm) minimum penetration depth, while the Texas DOT requires 0.23 in. (approximately 6 mm).

DISCUSSION

Tests such as water absorption, chloride penetration, and alkali resistance are performed in conditions where the treated specimens are placed in a situation to promote capillary uptake or under immersed conditions with very low pressure (water bath). These conditions do not apply severe stress on the sealers as they only need be present at the surface to be effective.

Table 2 shows the results of five products (all complying with EN 1504-2) with regards to their water absorption and resistance to alkali. If only these tests were to be considered, it seems obvious that Product 3 or even Product 1(a) show the best results.

These results are confirmed when we compare these products (Product 1(b) has the same molecule as Product 1(a) but with slightly higher active content) when tested with NCHRP 224 test methods (refer to Table 3).

Product 1(b), when exposed to UV, shows some level of degradation but it does not seem to affect the performance in term of soluble chloride reduction or water absorption. In regards to this light deterioration, there are no significant differences between the different products presented, and if we assume that the cost of the materials is directly related to the active content, then these two products 1(a) and 1(b) seem to have the best performance/cost ratio.

So based on these test methods, either from the European standard or from the American Highway Research Program, the ranking would be as shown in Table 4.

Now, if we compared these products to their ability to penetrate the concrete, then the picture will look completely different. The same products (1(a), 2, 3, 4, and 5) were applied at different consumption rates with two different types of artificially carbonated[3] concrete.

The penetration depth clearly shows the importance of the active content because for a similar consumption rate, the active content is directly proportional. Actually, Product 3 (solvent-based

TABLE 1: EN 1504-2 PERFORMANCE CRITERIA FOR HYDROPHOBIC IMPREGNATION

Item	Performance characteristics	Criteria
1	Initial water absorption	<7.5% to the untreated specimen
2	Water absorption after alkali stress	<10% to the untreated specimen
3	Loss of mass after freeze-thaw-salt stress	Loss of material must occur at least 20 cycles later than the untreated specimen
4	Drying rate	Class I: >30% Class II: >10%
5	Penetration depth	Class I: <0.39 in. (10 mm) Class II: ≥0.39 in. (10 mm)

TABLE 2: WATER ABSORPTION AND ALKALI RESISTANCE AS PER EN 13580

	Product 1(a) Solvent-based siloxane	Product 2 Water-based silane	Product 3 Solvent-based silane/siloxane	Product 4 Silane	Product 5 Silane cream
Active content, %	<10	approximately 40	approximately 30	approximately 99	approximately 80
Water absorption, %	2.5	5.2	1.0	3.8	5.1
Resistance to alkali, %	8.2	9.1	2.7	6.7	8.3

TABLE 3: NCHRP 224 REPORT

	Product 1(b) Solvent-based siloxane	Product 2 Water-based silane	Product 4 Silane	Product 5 Silane cream
Active content, %	approximately 15	approximately 40	approximately 99	approximately 80
Application rate, in. ft^2/gal. (mmL/m^2)	125 (325)	125 (325)	125 (325)	184 (222)
Series IV Southern exposure				
Resistance to UV light	Very slight scaling	No discoloration	No discoloration	No discoloration
Reduction to soluble chloride, %	97.6	79	98	93
Series II				
Reduction to water absorption, %	87	Not determined	Not determined	81
Reduction in chloride ion content, %	95	96	92	86

TABLE 4: RANKINGS

Product	Type	Ranking as per EN 1504-2	Ranking as per NCHRP
Product 1(a)	Solvent-based siloxane <10%	Second	Not determined
Product 1(b)	Solvent-based siloxane approximately 15%	Not determined	First
Product 2	Water-based silane approximately 40%	Sixth	Third
Product 3	Solvent-based silane/siloxane approximately 30%	First	Not determined
Product 4	Silane approximately 99%	Fourth	Second
Product 5	Cream approximately 80%	Fifth	Fourth

30% active content) penetrates better than the water-based silane due to its solvent carrier, even if its active content is lower.

Various authors[2,4,5] have highlighted the need for a proper penetration depth to ensure durability of the treatment with hydrophobic sealers.

Wittmann,[2] in his investigation of the use of hydrophobic impregnations in marine structures, has shown that to be effective against the actions of waves or tides, the hydrophobic sealers should penetrate at least 0.16 to 0.23 in. (4 to 6 mm) into the substrate.

Freitag and Bruce[4] presented a detailed review for the New Zealand bridge authorities in which he stressed the need to differentiate product performances based on their ability to penetrate.

Dai et al.[5] presented a study where different hydrophobic sealers were used with various consumption rates. He demonstrated that low active content siloxane material (similar to Products 1(a) or 1(b) presented in Tables 2 and 3) were not effective in preventing chlorides from penetrating or arresting corrosion in cracked concrete (refer to Fig. 3).

The study also shows that if a good product (high active content similar to Product IV presented in Tables 2 and 3) was used at a low consumption rate yielding an insufficient penetration, then its effectiveness is reduced when applied before the cracks occur. Finally, the study shows that if a good product (cream or gel type) is applied correctly with a high penetration depth, then the effectiveness remains high to prevent corrosion of the reinforcement, even when applied before the cracks occur.

CONSUMPTION DILEMMA

Johansson et al.[1] has shown that penetration depth of various silane molecules available in the market is dependent on different parameters, such as porosity, time of contact, and degree of saturation into the concrete. The time of contact for the treatment is directly related to the consumption.

Figure 4[1] shows the penetration depth of a silane (similar to Product IV mentioned earlier in the paper) applied on different quality concretes with variable contact time (equivalent to variable consumption rate).

Figure 5[1] shows that even with a very porous concrete (w/c = 0.80), a pure silane cannot migrate easily into a moisture-saturated substrate.

Johannson et al.'s[1] paper clearly proves that due to the variation of site conditions (age of concrete, its porosity, and moisture saturation),[*] a given consumption rate cannot cater to all situations.

[*]Not mentioning the substrate surface preparation.

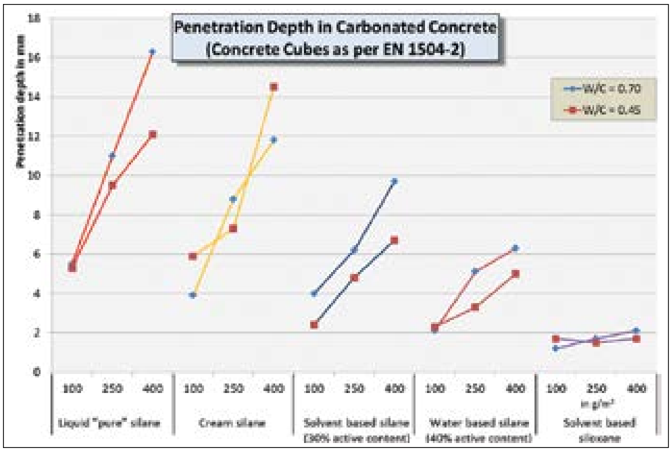


Fig 2: Penetration depth of different hydrophobic sealers according to consumption rate (Note: 1 mm = 0.04 in.)

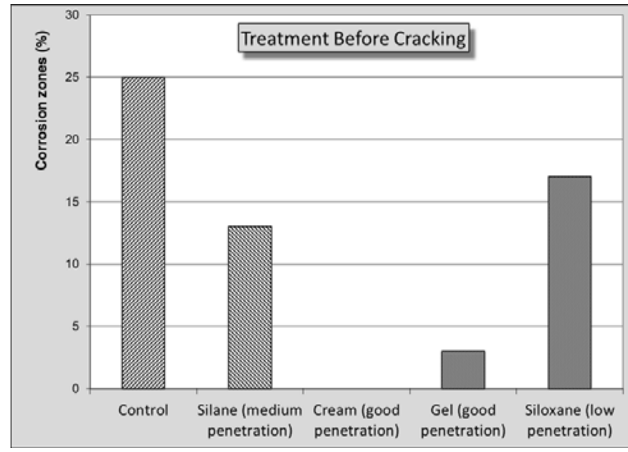


Fig 3: Corrosion of cracked reinforced concrete after 1 year of accelerated cycles with seawater

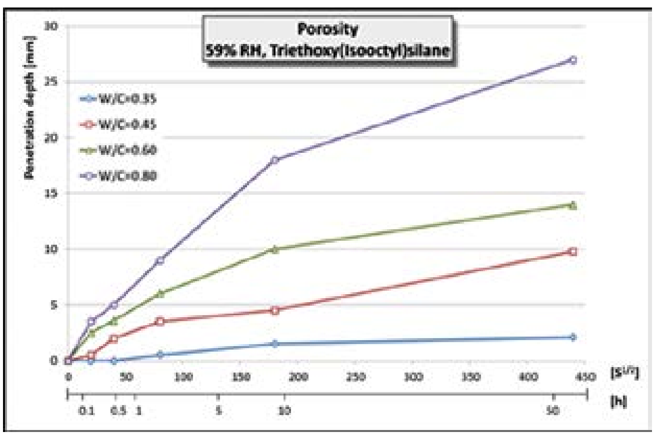


Fig 4: The influence of porosity on the effective penetration depth. The time on the x-axis is the duration of contact for the treatment. The penetration depth is measured 4 months later (Note: 1 mm = 0.04 in.)

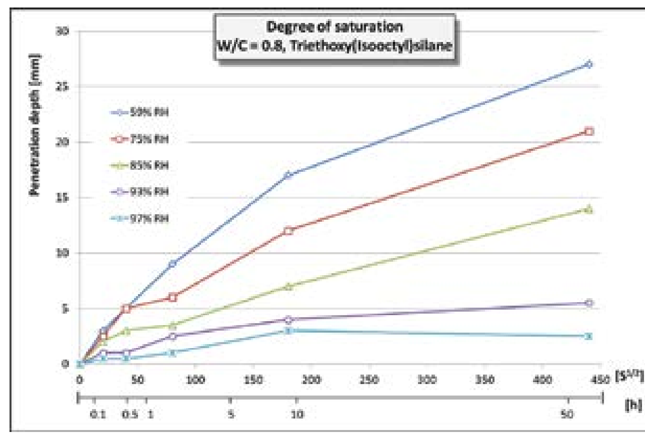


Fig 5: The influence of the conditioning environment around the specimen. The time on the x-axis is the duration of contact for the treatment. The penetration depth is measured 4 months later (Note: 1 mm = 0.04 in.)

Fig. 6: Overhead airless spray application of a pure silane

Fig. 7: Silane cream

Fig. 8: Silane cream applied at the crown of the Gothard tunnel in Switzerland. 64,600 ft^2 (approximately 6000 m^2) were treated overnight with airless spray application

If durability of the treatment is of concern, it is then necessary to conduct some preliminary investigation to assess the relevant consumption rate required to achieve the targeted penetration depth.

An example of penetration depth versus consumption rate is given in Fig. 2.

Using this example, if the penetration depth target for the carbonated concrete with $w/c = 0.45$ was more than 0.20 in. (5 mm), the graph shows that when using the cream silane, only 0.02 lb/ft^2 (100 g/m^2) was necessary to achieve that target (three times lower than the typical consumption recommended by the manufacturer). This shows that by optimizing the consumption rate, not only will durability be achieved but also a substantial cost saving.

This preliminary test will also allow users to determine the optimized surface preparation to remove the surface pollution that might prevent the hydrophobic sealer to migrate properly.

NEW TECHNOLOGY

As mentioned previously, it is of paramount importance to control the consumption rate at the job site if a targeted penetration depth/specific performance is required.

For example, in a project[6] in the Czech Republic, a sealer was needed to improve the freezing-and-thawing resistance of high-strength concrete. After relevant testing, it was shown to achieve the targeted objective but would require at least 0.08 lb/ft^2 (400 g/m^2).

The selected product for this project was a pure silane (similar to Product IV mentioned in Tables 2 and 3). To achieve this targeted consumption rate, it was necessary to apply the product in various layers (up to five layers).

Application was conducted on site directly on the bridge beams (Fig. 6). In these conditions (overhead application, windy conditions, liquid product), it was difficult for the workers to properly control the consumption rate during application.

There is a high risk of spillage and evaporation during the application, yielding some risk of failing to meet the objective consumption rate.

To compensate for these difficult site conditions, a new technology had been developed in Europe and involved making silane into a cream or gel-type material.

It exists in two forms in the market: a water-based cream (refer to Fig. 7) having approximately 80% active content (similar to Product V described in Tables 2 and 3) and a solvent-based gel with approximately 90% active content (similar to the gel product mentioned in the Dai et al.[5] paper). Both products have outstanding penetration behavior.

Due to their consistency, these products can be applied in higher consumption rates, therefore reducing the number of layers required.

Additionally, during application (especially overhead or vertically), there is reduced waste due to dripping or evaporation. The applicator can easily see where the product has been applied; the substrate remains whitish for a while in the case of the cream application. As the product "sits" at the surface for a given time, the silane molecules can easily migrate in the concrete.

Once the cream product has been applied, it will migrate within the substrate, leaving no trace of its presence and does not require additional treatment, such as power washing. On the other hand, the gel product, after having migrated in the substrate, leaves a deposit at the surface of the concrete. This residue needs to be washed away by power cleaning.

Thanks to its consistency, using a cream-type product for specific site conditions allows for a safe, fast, and efficient application (Fig. 8).

In summary, this article outlines the different hydrophobic sealer technologies available to treat different mineral substrates seen on the job. It also shows the importance of the right selection criteria (for example, penetration depth) in selecting a suitable product for specific project requirements.

As many other authors have also mentioned, it is critical to stress the importance in determining the penetration depth as key specification criteria to achieve the targeted durability.

It has also been demonstrated that by controlling the correct consumption rate according to the targeted penetration depth, not only will durability be achieved but also cost savings.

Finally, a "new[†]" technology has been presented for the North American market, showing that by using a cream silane, a safer, faster, and more efficient application can be achieved.

REFERENCES

1. Johansson, A.; Marten, J.; Silfwerbrand, J.; and Tragardh, J., "Penetration Depth for Water Repellent Agents in Concrete as a Function of Humidity, Porosity and Time," *Restoration of Buildings and Monuments*, V. 13, No. 1, pp. 3-16.

2. Wittmann, M., et al., "Application of Water Repellent Treatments for the Protection of 'Offshore' Constructions," *Hydrophobe III—3rd International Conference on Surface Technology with Water Repellent Agents*, Faculty of Mechatronics and Sciences, University of Applied Science Karlsruhe, Germany, 2001.

3. Internal tests by MPL, Sika Technologies AG, Apr. 2012.

4. Freitag, S. A., and Bruce, S. M., "The Influence of Surface Treatments on the Service Lives of Concrete Bridges," NZ Transport Agency Research Report 403, 2010, 91 pp.

5. Dai, J., et al., "Investigation of Chloride Ingress in Cracked Concrete Treated with Water Repellent Agents," *Hydrophobe V, 5th International Conference on Water Repellent Treatment of Building Materials*, 1Ufe Cycle Management Research Centre, Port and Airport Research Institute, Japan, 2008, pp. 299-310.

6. Expert *Report* No. 10 0027-III, Klokner Institute, Czech Technical University, Prague, Czech Republic, Nov. 2011.

[†]In Europe, these products were first introduced in the late 1990s.

Aamer Syed *is the Senior Product Marketing Manager–Repair Systems for Sika Corporation and is based at the Lyndhurst, NJ, corporate office. Sika Corporation is a worldwide producer of concrete admixtures, repair materials, waterproofing, roofing, and flooring products with over 90 years of history in construction chemicals. Syed received his BS in mechanical engineering in 1995 from NED Engineering University in Karachi, Pakistan. He completed his Master's in Management Program at Stevens Institute of Technology, Hoboken, NJ, in 2003. Syed's work experience includes representing Hilti Corporation for 4 years. He joined Sika Corporation in 1998 as a Test Engineer. Syed's current responsibilities include Product Management of Sika's cement-based materials, including mortars, grouts, epoxy resin materials, and other refurbishment systems. Syed is a member of ICRI, ACI, NTPEP, and PTI at the national level, where he participates in various technical committees. He was appointed member of the ICRI Technical Activities Committee in 2013.*

Michel Donadio *is the Technical Manager of the Refurbishment Market Field of the corporate organization within the Sika group (Sika Services AG), a position held since 2009. He is responsible for concrete repair and concrete protection with hydrophobic impregnation and protective coating, corrosion inhibitor, and more. Donadio graduated with a degree in chemistry in France in 1979. He started his career with Lafarge cement in various countries, including France, Gabon, Venezuela, Algeria, and Somalia. He joined Sika in France in 1986 as a Mortar Lab Manager, then as Technical Manager for 10 years in Malaysia. Upon his return from Asia, Donadio started with Sika Services AG as a Corporate Product Engineer based in Switzerland.*