Composite Coatings with Silanes for Protecting Reinforced Concrete in Salt Water Environment

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Abstract
Reinforced concrete structures ae used along the coasts and also in rivers and canals to support various structures including bridges. When reinforced concrete is exposed to water and salt water (15% NaCl) the steel reinforcements corrode faster and are becoming big challenge maintain the infrastructures. In this study silane coatings with and without latex coating the on concrete specimens where evaluated to quantify the saltwater and pure water infiltration with time and tests were performed for 21 days. Also drying of the coated concretes were evaluated. Of the single and composite coatings tested, silane coating alone was very effective minimizing the water and saltwater infiltration into the concrete.

1.Introduction

Corrosion in reinforced concrete structures is raising increasing concern because it requires immediate repairs and rehabilitation to extend the service life of the structures. Concrete bridge structures are undergoing accelerated deterioration in the coastal regions owing to the corrosion of the embedded reinforcing steel. Corrosion could be attributed to gradual intrusion of chloride ion and moisture into the concrete from deicing salts which is further accelerated by the salt water environment in the coastal regions. Deterioration caused by corrosion of reinforcing steel is not limited to bridge decks only but also affects other bridge members such as abutments, beams, crossbeams, diaphragms, piers, and piles. Steel corrosion is accelerated when the protective concrete cover over the embedded bars is inadequate and where there are cracks which accelerate the migration of moisture and salt.

Corrosion in reinforced concrete is controlled by three mechanisms as diffusion, corrosion, and deterioration; but the diffusion period is the most critical. It must be noted that the deterioration stage will not start if the chloride concentration level is relatively low. Since reinforcement corrosion is dependent on the availability of moisture, oxygen and chlorides, any methodology to reduce their ingress into the concrete mass will reduce concrete deterioration.

One of the methods to stop the ingress of corrosion causing agents into the concrete mass is by constructing a barrier on the concrete surface using a suitable coating or sealer. Materials used to protect concrete in corrosive environments include epoxies, methacrylate, urethane, silicate, siloxane and silanes. Silane is a organic coating with multiple Si-C- bonding capabilities. Penetrating sealers such as silane, penetrates into the concrete and makes the concrete surface hydrophobic whereas a coating forms a film on the surface and blocks the pores and cracks on the concrete surface. Most sealers are not permanent hence periodic reapplications may be necessary to maintain the protective properties of the sealers. To provide long term durability by protecting the sealers and avoid their reapplication, the potential of resisting chloride and moisture intrusion by a combination of sealer with coating was investigated in the current study.

Performance of the silanes and coatings could be evaluated by monitoring the weight change of coated concrete specimens immersed in corrosive environment. This change in weight of coated concrete could be used as a measure for degree of deterioration of the concrete and hence, the prediction of the weight change is very important for predicting the service life of coated concrete. Mathematical modeling of the weight change phenomenon can help in determining the coating parameters, which could be used in evaluating the effectiveness of coating materials. To evaluate the quality of concrete in resisting solution intake a weight change model for concrete cylinders without coating has been developed by the CIGMAT researchers in 1995. A thin film model has been developed by the CIGMAT researchers to evaluate the performance of coating for the immersion or wetting phase. These models can be used to investigate the concrete treated with coatings and silanes.

2.Objectives

The overall objective of this study was to investigate the effectiveness of combining sealers with coating to protect the concrete from chloride and moisture intrusion. Two silanes, (Silane-1 and Silane-2) with a latex coating (Coating-1) were used. The specific objectives were as follows:

1. Develop a test procedure to evaluate the effectiveness of silane treatment, with and without latex coating, in controlling the water and 15% sodium chloride solution diffusion/infiltration (Immersion Test for 21 days) and exfiltration/breathing (Drying Test for 21 days) in concrete .
2. Quantify the changes in weights under the selected wetting and drying testing conditions and compare the performance of the composite coatings.
3. Identify the test for evaluating the coatings for protecting reinforced concrete.

3. Materials

Commercially available two silane coatings denoted as Silane-1 and Silane-2 were applied with the latex based coating denoted as Coating-1 to the concrete substrate. Silane-1 was a micro-emulsifiable concentrated alkoxysilane. The typical dilution used was 9 parts of water to 1 part silane (volume based), although varying dilutions can be used to achieve different degrees of water repellency. Silane-2 was clear, penetrating, and breathable water repellent designed for the protection of exterior above-grade concrete. It penetrates the surface and bonds chemically to the substrate, resulting in permanent attachment of the water repellent molecule. Coating-1 was water based latex coating with rapid drying, good adhesion, and high flexibility. Coating-1 was applied using rollers. Application temperature was 65°F. The coated surface was left to dry for four days before testing. Some of the properties of two pure silane coatings and latex coating are summarized in Table 1.

Table 1 Properties of Two Silane Coatings and One Latex Coating

Silane Material	**Physical State**	**Density (kg/m^3)**	**Silane Content (%)**	**Flash Point (ºC)**
Silane-1	Liquid	1000	100	77
Silane-2	Liquid	760	40	>100
Coating Material	**Physical State**	**Density (kg/m^3)**	**V.O.C.* (gm/L)**	**Solids by Weight (%)**
Coating-1 (Latex Based)	Liquid	1365	104	53.50

*V.O.C is volatile organic carbon

Cylindrical concrete specimens (6 inch diameter x 6 inch height) were obtained from an on-site concrete batch plant used for constructing a bridge across a causeway near the coastline. The Concrete specimens (cylinders) had an average unit weight of (based on 20 specimens) 140.2 pcf, standard deviation of 0.9 pcf, COV (coefficient of variation) of 0.64%, and an average compressive pulse velocity of 13,353 ft/sec (4070 m/s).

SAMPLE PREPARATION AND TESTING PROGRAM

The experiments were performed at the University of Houston CIGMAT laboratory. The test program comprised of coating the concrete specimens, immersion in selected solutions followed by drying at room condition. Concrete specimen were cured for 28 days then cleaned and dried prior to the application of silanes and the coating. Concrete surface was cleaned using a water blaster. The specimens were dried at room condition for one day before spraying the silane sealer. The silanes were applied by spraying onto the surface using 15 psi (103 kPa) low pressure positive displacement airless spray equipment. The application temperature was 19°C. After applying the silane sealer, the specimens were left to cure for 5 days before applying the Coating-1 (latex-based). The coating was applied using a roller. The coating was white in color and the application temperature was 19°C. The specimens were weighed during the coating cycle accurately to 0.01 gms. Addition of Coating-1 to the specimens changed the weight of the specimen by about 3%. The coated specimens were cured at room condition for 21 days before immersing in water and 15 % NaCl solution.

The specimens were totally immersed in selected test solutions in closed immersion jars. The two test solutions selected for the study were (1) tap water (pH = 7 to 9) and (2) 15% NaCl solution (representing the accelerated test condition in marine system) as recommended by NCHRP 244 (National Cooperative Highway Research Program Report). In this test, changes in weight of specimen and appearance of specimen were monitored for 21 days (CIGMAT CT-1, ASTM G 20).

In order to study the drying pattern of coated concrete, also the NCHRP 244 method was used. The weight changes in the coated concrete were monitored at regular intervals up to 21 days. In Figure 1 the drying of the coated specimens under room condition (temperature 23^{o}C and relative humidity 55%) are shown.

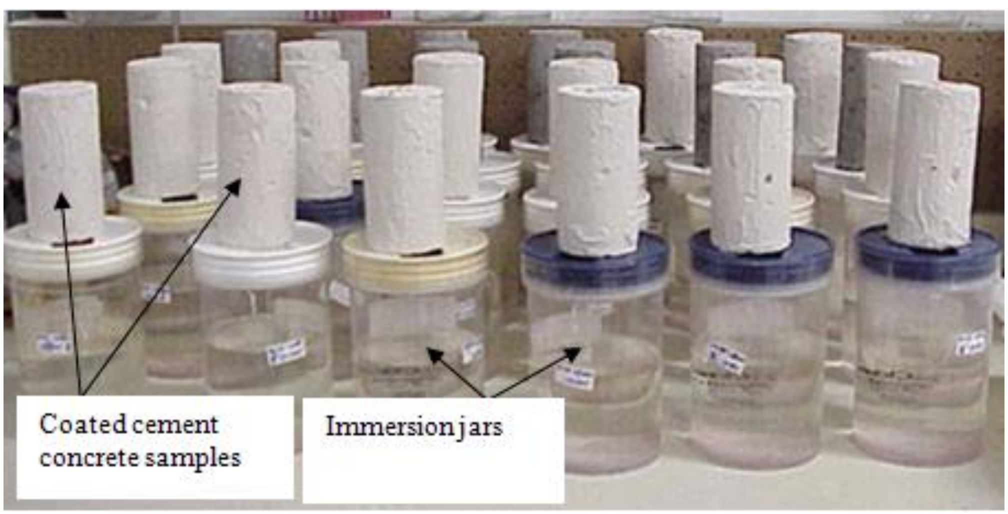

Figure 1. Specimens being dried for measuring the weight change during the drying cycle

4.TEST RESULTS AND DISCUSSION

Wetting Phase (In Water)

The relationships between the percent weight change and time for coated specimens in water are shown in Figures 2 and 3 for silane-1 and silane-2 respectively. Based on the observed weight changes with time, in the first four days there is infiltration followed by diffusion of the water into the coated specimens. Test results are also summarized in Table 1.

Coating-1: The weight change in one day was 0.6%. It increased to 2.6% after 21 days of immersion. This had the highest change in the weight for all the coatings investigated.

Silane-1: The weight change in one day was 0.3%. It increased to 1.1% after 21 days of immersion. This had the second lowest change in the weight for all the coatings investigated.

Silane-1 and Coating-1: The weight change in one day was 0.5%. It increased to 2.3% after 21 days of immersion. This had the second highest change in the weight for all the coatings investigated.

Silane-2: The weight change in one day was 0.1%. It increased to 0.7% after 21 days of immersion. This had the lowest change in the weight for all the coatings investigated.

Silane-2 and Coating -1: The weight change in one day was 0.6%. It increased to 1.2% after 21 days of immersion. The overall performance after 21 days was comparable to Silane-1 coating.

Summary: The average weight increase in water after 21 days, for specimens coated with Silane-1 was 1.1% as compared to 0.7% for specimens coated with Silane-2. Similarly weight increase for specimens coated with Silane-1 and Coating-1 combination was 2.3% as compared to 1.21% for Silane-2 and Coating-1 combination. Maximum weight gain was observed for specimens coated with Coating-1 as compared with any other combination. This implies that Coating-1 absorbed more water and governed the water intake for cases where Coating-1 was the outer layer.

Wetting Phase (In 15% NaCl solution)

The relationships between the percent weight change and time for coated specimens in 15% NaCl solution are shown in Figures 4 and 5 for silane-1 and silane-2 respectively. Based on the observed weight changes with time, in the first four days there is infiltration followed by diffusion of the water into the coated specimens. Test results are also summarized in Table 2.

Coating-1: The weight change in one day was 0.6%. It increased to 2.6% after 21 days of immersion. This had the highest change in the weight for all the coatings investigated.

Silane-1: The weight change in one day was 0.3%. It increased to 1.1% after 21 days of immersion. This had the second lowest change in the weight for all the coatings investigated.

Table 1. Weight Changes in Coated Concrete Specimens during the Water Wetting Cycle

Coatings	**Percentage Weight Gain in Wetting Time (Days)**				**Remarks**
	1	**4**	**10**	**21**	
Coating-1	0.7%	2.3%	2.4%	2.6%	Highest change in weight.
Silane-1	0.3%	0.6%	0.75%	1.1%	Second lowest change in weight.
Silane-1 and Coating-1	0.5%	1.8%	2.0%	2.3%	Second highest change in weight.
Silane-2	0.1%	0.4%	0.5%	0.7%	Lowest change in weight.
Silane-2 and	0.6%	1.1%	1.2%	1.2%	Slightly higher

Coating-1					than Silane-1.
Remarks	Silane-2 had the lowest weight change	Coating-1 had the highest weight change	Silane-1 had the second lowest weight change	Weight changes were sensitive to the type of coating	Of all the coatings investigated, Silane-2 had the lowest weight change

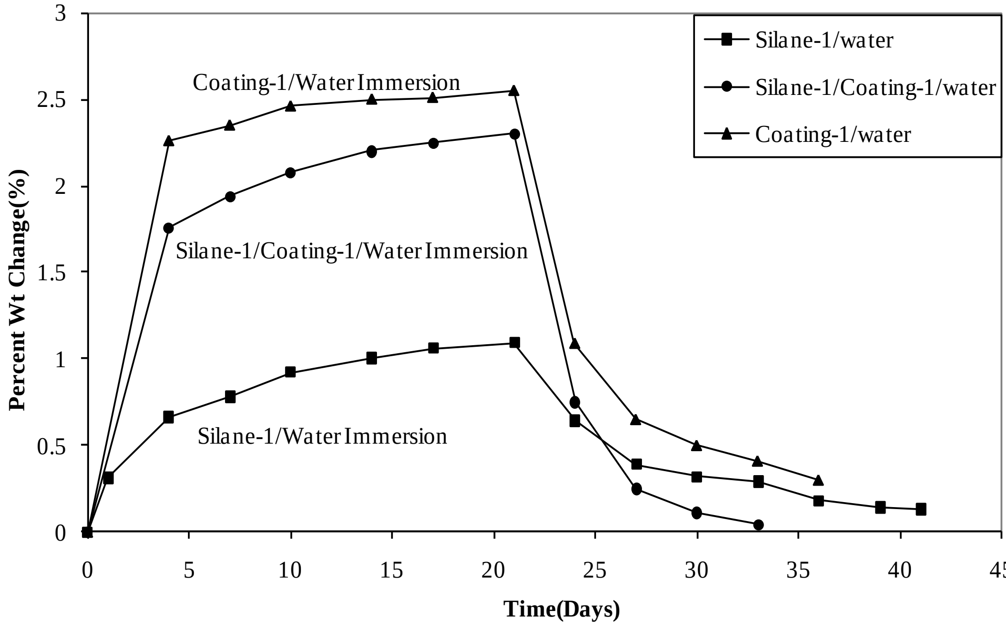

Figure 2 Change in weight for concrete in water coated with Silane-1 and Coating-1

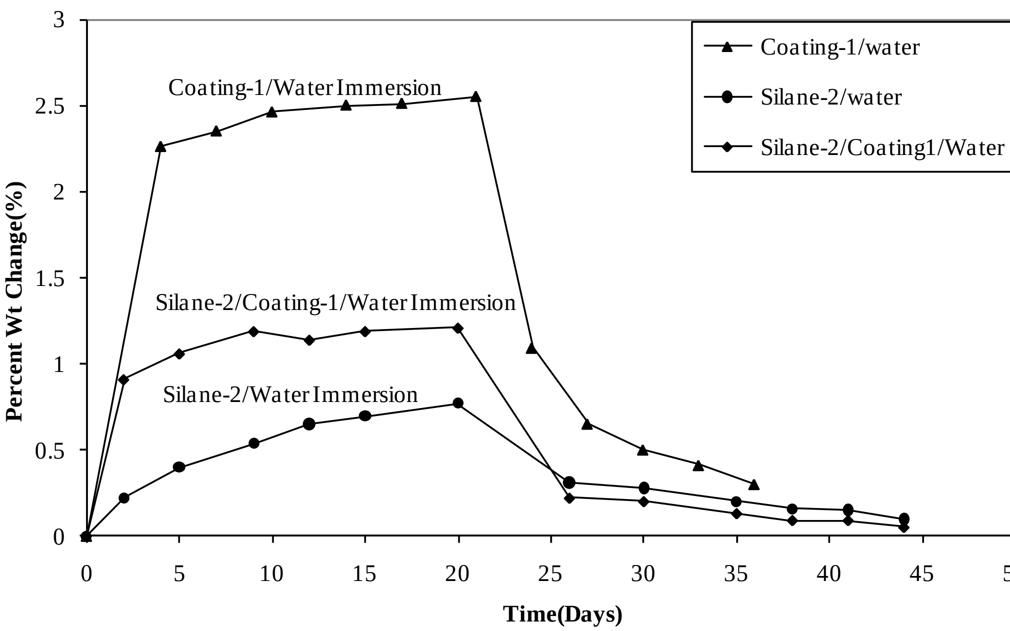

Figure 3 Change in weight for concrete in water coated with Silane-2 and Coating-1

Silane-1 and Coating-1: The weight change in one day was 0.5%. It increased to 2.3% after 21 days of immersion. This had the second highest change in the weight for all the coatings investigated.

Silane-2: The weight change in one day was 0.1%. It increased to 0.7% after 21 days of immersion. This had the lowest change in the weight for all the coatings investigated.

Silane-2 and Coating -1: The weight change in one day was 0.6%. It increased to 1.2% after 21 days of immersion. The overall performance after 21 days was comparable to Silane-1 coating.

Summary: Weight increase in 15% NaCl solution after 21days, for specimens coated with Silane-1 was 0.7% as compared to 0.2% for specimens coated with Silane-2. Similarly weight increase with specimens coated with Silane-1 and Coating-1 combination was 2.1% as compared to 1.5% for Silane-2 and Coating-1 combination. Weight gain of specimens coated with Coating-1 was similar with specimens coated with Silane-1 and Coating-1, which reinforces the fact that Coating-1 governed the solution uptake in the cases where Coating-1 was the outer layer. However it can be observed that combination of Silane-2 and Coating-1 was more effective in resisting the solution intake in all cases as compared to Silane-1 and Coating-1 combination.

Table 2. Weight Changes in Coated Concrete Specimens during the 15% NaCl Wetting Cycle

Coatings	**Percentage Weight Gain in Wetting Time (Days)**				**Remarks**
	1	**4**	**10**	**21**	
Coating-1	0.5%	1.8%	2.0%	2.0%	Highest change in weight.
Silane-1	0.2%	0.4%	0.6%	0.7%	Second lowest change in weight.
Silane-1 and Coating-1	0.5%	1.6%	2.0%	2.1%	Second highest change in weight.
Silane-2	0.1%	0.15%	0.18%	0.2%	Lowest change in weight.
Silane-2 and Coating-1	0.5%	1.2%	1.4%	1.5%	Performed better than composite coating Silane-1 and Coating-1.
Remarks	Silane-2 had the lowest weight change	Coating-1 had the highest weight change	Silane-1 had the second lowest weight change	Weight changes were sensitive to the type of coating	Of all the coatings investigated, Silane-2 had the lowest weight change

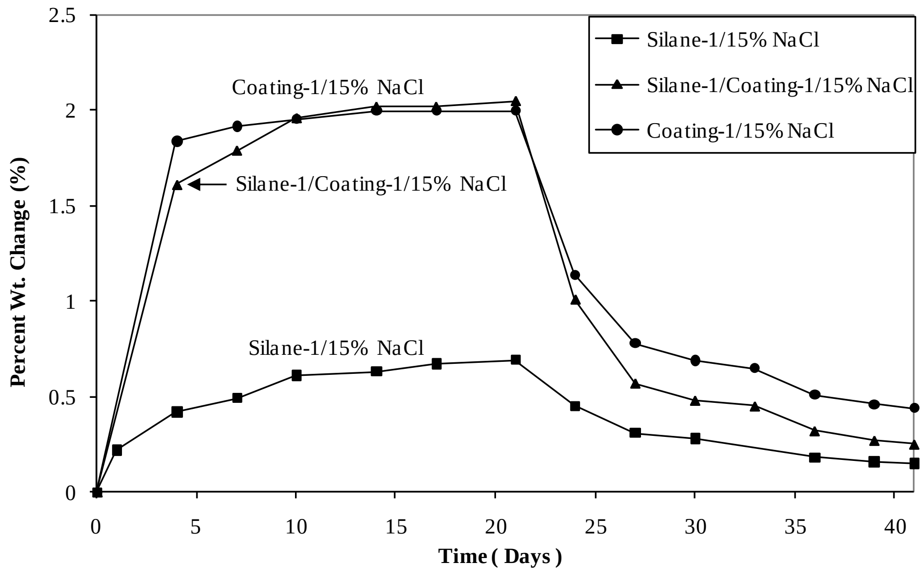

Figure 4 Change in weight for concrete in 15% NaCl solution coated with Silane-1 and Coating-1

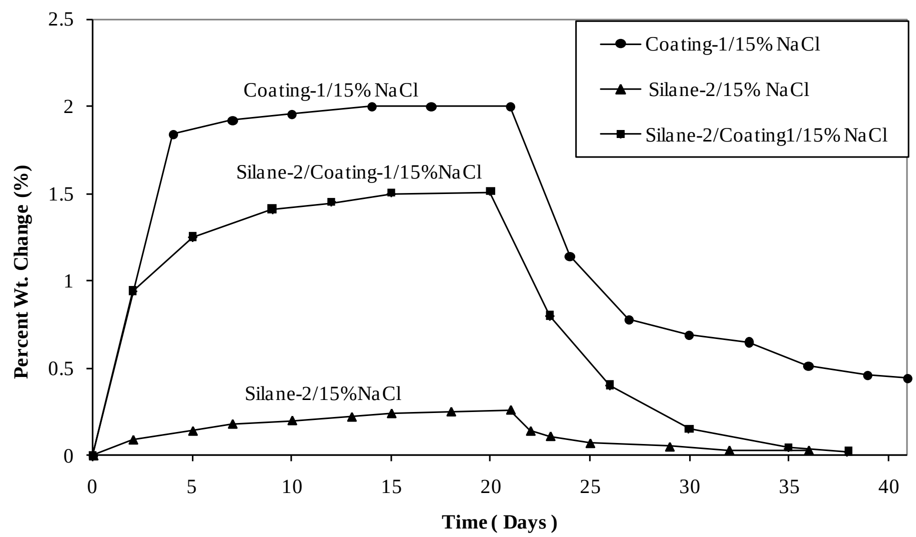

Figure 5 Weight change of specimens in 15% NaCl solution coated with Silane-2 and Coating-1

Drying Phase

The drying results are compared in Figures 2, 3, 4 and 5. Most of the weight changes were observed during the first six days of drying, where the testing water and salt solutions evaporated. The residual solution in the specimens at the end of drying phase reduced to zero for the Silane-1 and Coating-1 combination as compared to 0.05% for the combination of Silane-2 with Coating-1 when immersed in water. However Silane-2 with Coating-1 proved to be a better combination over Silane-1 with Coating-1 when immersed in 15% NaCl solution as it drained out all the solution at the end of the drying phase. Corrosion of reinforced concrete is very much influenced by the diffusion phase (long-term) and hence the immersion process should govern the selection of the coating type to be used for protecting structures.

5. Conclusions

Applicability of two commercially available silanes (Silane-1 and Silane-2) in combination with a latex based coating (Coating-1) in resisting absorption of water and 15% NaCl solution was investigated. The following conclusions are advanced:

1. The immersion and drying test method (21 days of immersion followed by 21 days of drying), relatively a quick test method was effective in identifying the differences in performance of the single coatings and composite coating.
2. In this study, Silane-2 alone preformed the best in water and also 15% NaCl solution and clearly identified the coating to be used for reinforced concrete piles and columns used along the causeway bridge along the coast.
3. Based on the test analyses of the results, just the immersion test can be used to evaluate the performance of coatings for concrete under different environments.

6. Acknowledgement

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7. References

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