Coatings and Sealers for Protecting Concrete Facilities

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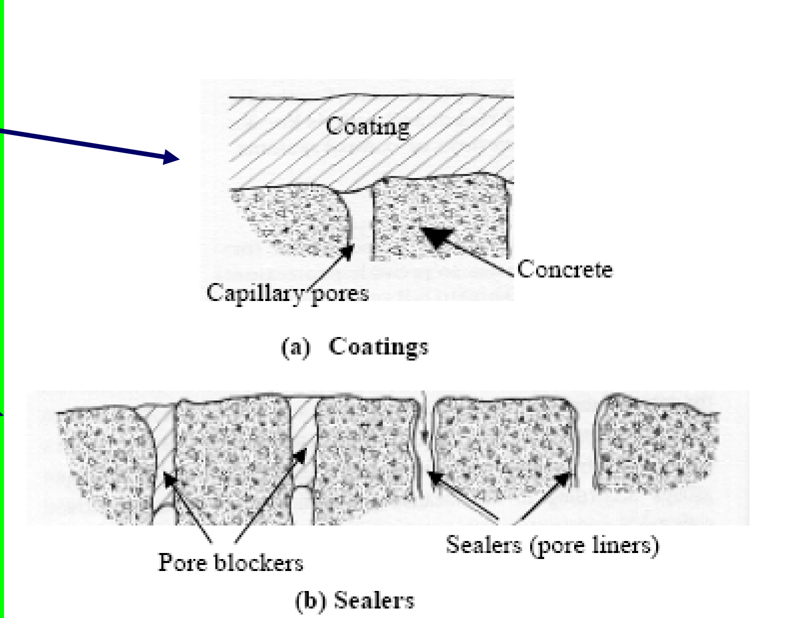
How?   When & Where? Why?

1. Coating Forms A Barrier:

2. Sealers Makes it Less Permeable



3. Corrosive Environment

4. Control Moisture Movements

5. Easy to Apply, Rapid Results & Cost Effective (Saves $$)

What are the Technologies ?

Corrosion Prevention / Maintenance

(i) Coatings

(ii) Linings

(iii) Chemical Spraying

Structural Rehabilitation

(i) Sliplining

(ii) Cure-in-place-pipe (CIPP)

(iii) Grouted Liners/Composites

OBJECTIVES

The overall objective of this study was to investigate the performance of coated concrete (coatings, sealers) under various environments.

The specific objectives are as follows:

(1) to evaluate the applicability of the coatings on concrete surface under hydrostatic back pressure

(2) to determine the long-term performance of coated concrete/clay brick with and without pinholes in sulfuric acid and salt environments.

Laboratory Study

On

Coatings

Table 9.1 Types of Failures according to the CIGMAT CT-2 Test

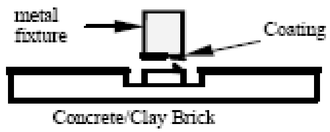
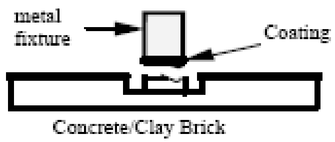
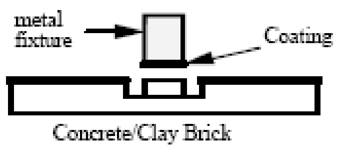
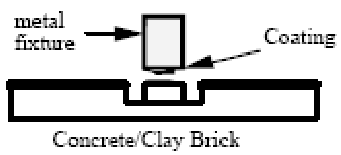
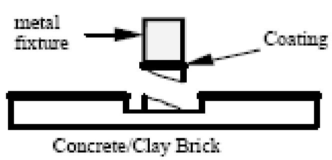
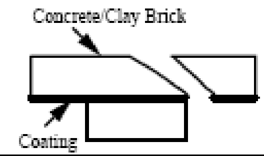
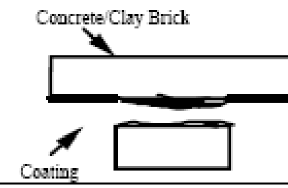
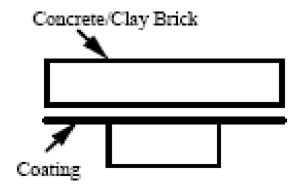
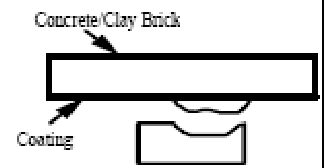
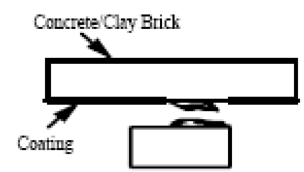
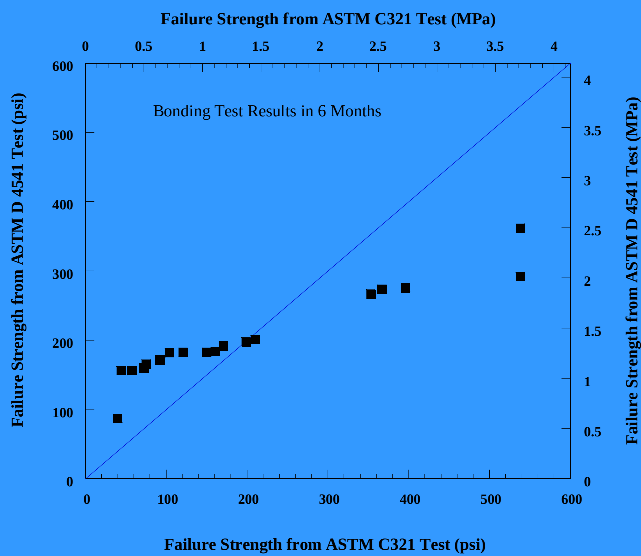
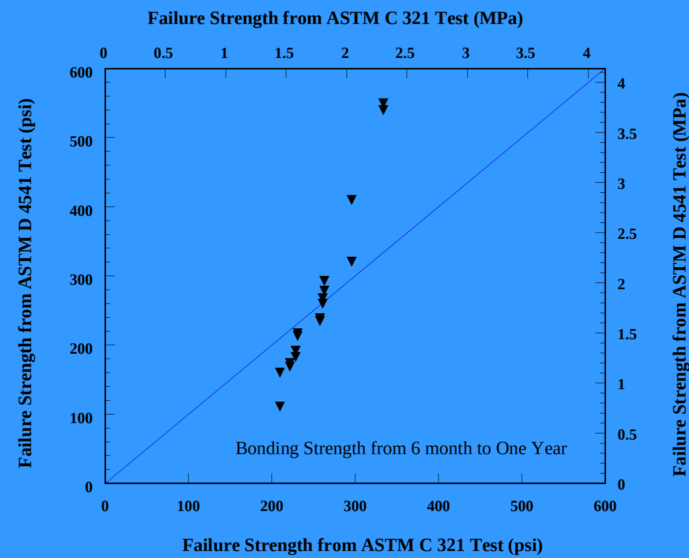
Failure Type	Description	CIGMAT CT 2 Test
Type-B1	Substrate Failure	
Type-B2	Coating Failure	
Type-B3	Bonding Failure	
Type-B4	Bonding and Substrate Failure	
Type-B5	Bonding and Coating Failure	

Table 9.2 Types of Failures according to the CIGMAT CT-3 Test

Failure Type	Description	CIGMAT CT-3 Test
Type B1	Substrate Failure	
Type B2	Coating Failure	
Type B3	Bonding Failure	
Type B4	Bonding and Substrate Failure	
Type B5	Bonding and Coating Failure	

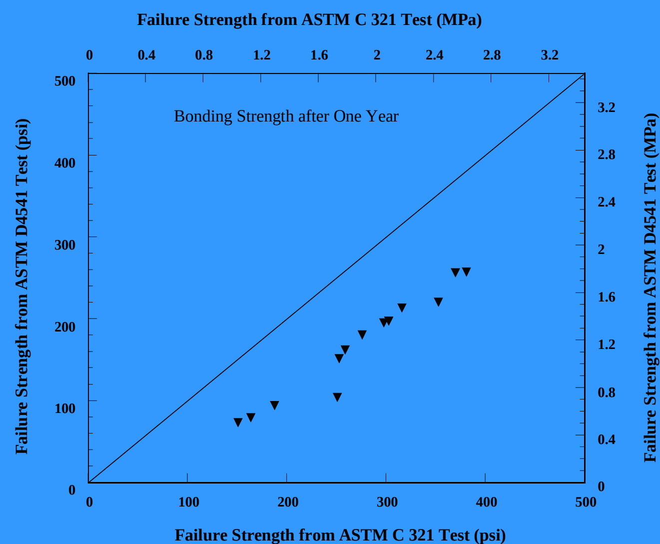
2. Comparison of Modified ASTM D 4541 and ASTM C 321 Tests





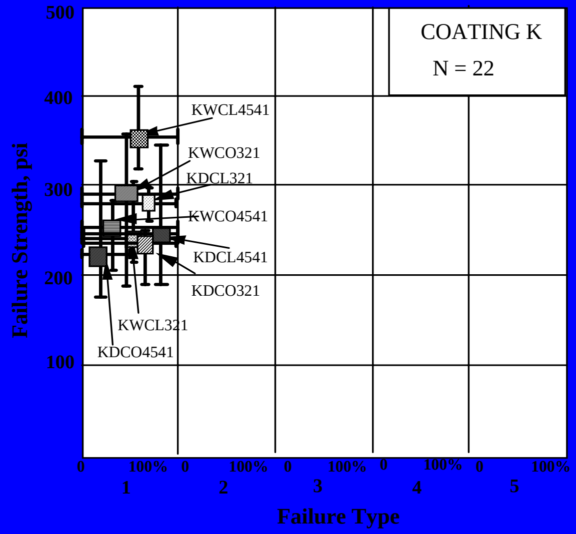
0 - 6 months

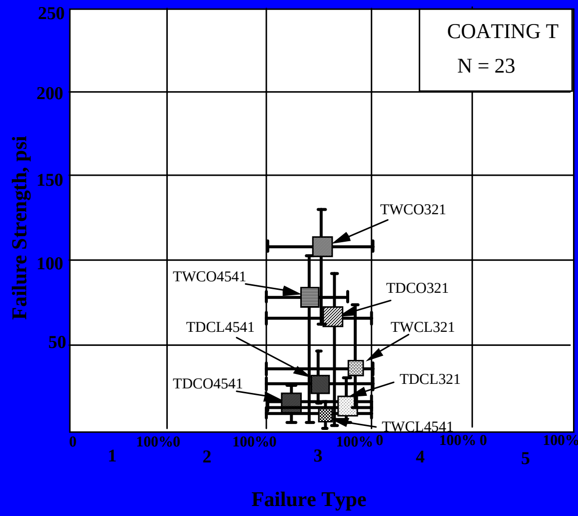
6 months - 1 year

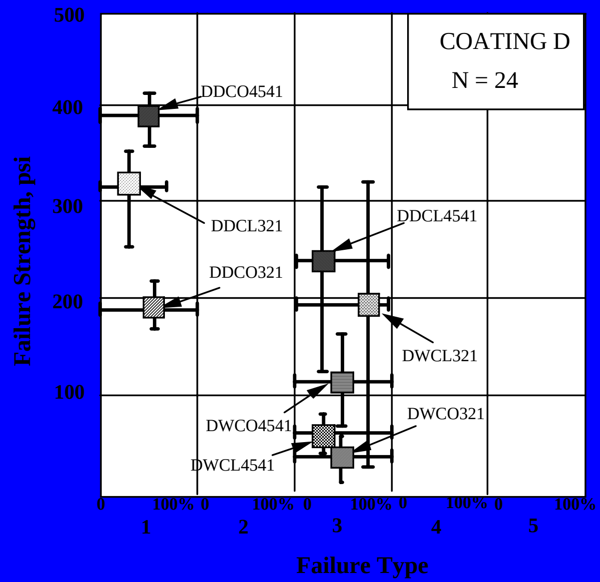


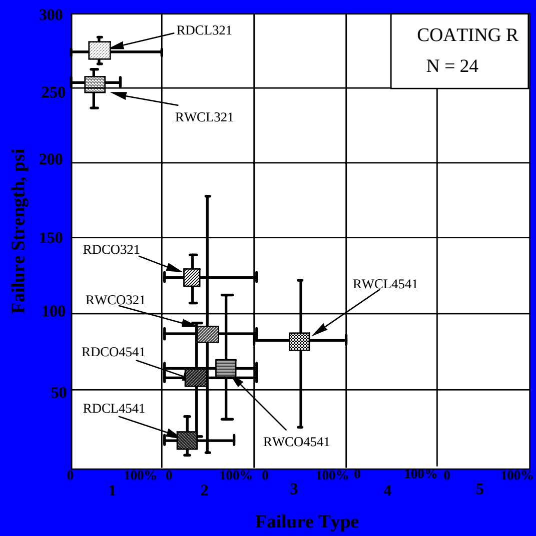
After 1 year

3. Bonding Failure Strength and Failure Types









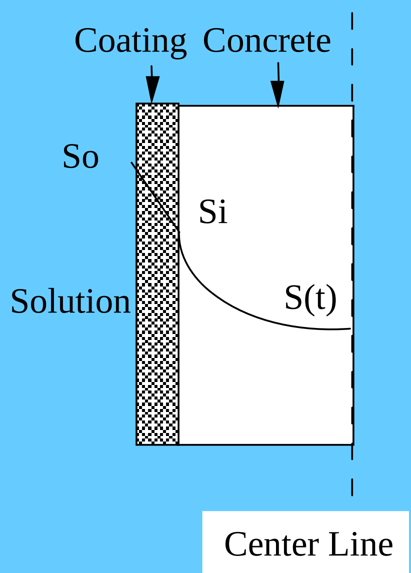
Field Study

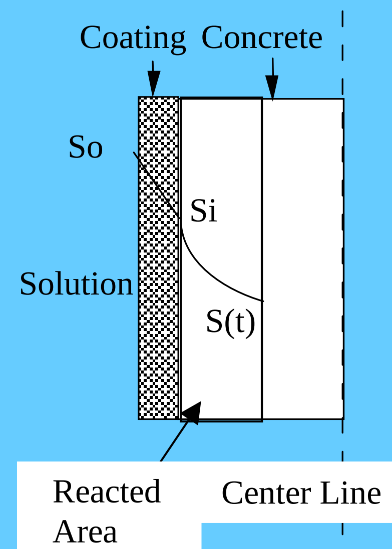
Vs.

Lab Study

Models for Liquid Transport into Coated Concrete and Calcium Leaching

1. Physical Model





Case 1: Liquid transport process without chemical reaction

Case 2: Liquid transport process with chemical reaction

2. Modeling

A. Assumptions:

(1) the process can be modeled by second order differential equation

$$\frac{\partial S}{\partial t} = D\left(\frac{\partial^2 S}{\partial x^2} + \frac{\partial^2 S}{\partial y^2} + \frac{\partial^2 S}{\partial z^2}\right)$$

(2) the mass transfer coefficient is constant in coating film (D_{CT}), non-reacted concrete cylinder (D_{CO}) or reacted concrete area ( );

(3) there is no gradient of degree of saturation between bulk liquid and D_{CO}^{r} coating surface;

(4) coating film and concrete surface are in good contact;

(5) coating film does not react with contacted liquid;

(6) degree of saturation of solid is defined as .

B. Liquid Transport through Coating Film

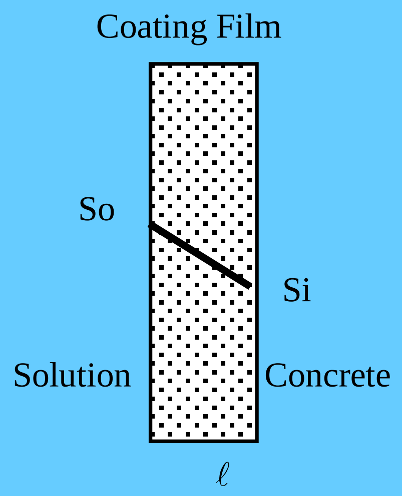
The second order differential equation in one dimension

$$\frac{\partial S}{\partial t} = D\frac{\partial^2 S}{\partial x^2} \qquad (1)$$

Boundary conditions:

at $x = 0$ $\quad S = S_0^{CT}$

$x = \ell$ $\quad S = S_i$



Solving equation (1)

$$\frac{S - S_0^{CT}}{S_i^{CT} - S_0^{CT}} = \frac{x}{\ell} \qquad (2)$$

Consider the rate of mass transfer F

$$F = -D_{CT}\left(\frac{\rho^{CT} dS}{dx}\right) \qquad (3)$$

Assume that the rate of mass transfer F is a constant from time t to t + dt combining equation (2) and (3), the rate of mass transfer at time t is

$$F_{(t)} = -D_{CT}\frac{dS}{dx} = \frac{D_{CT}}{\ell}\rho^{CT}\left(S_0^{CT} - S_i^{CT}\right) \qquad (4)$$

the concentration on the interface varying with time t can be represented by the exponential function

$$S_i^{CT} = S_0^{CT}(1 - e^{-\beta^{CT}t}) \qquad (5)$$

Equation (4) becomes

$$F_{(t)} = \frac{D_{CT}}{\ell}\rho^{CT}S_0^{CT}e^{-\beta^{CT}t} \qquad (6)$$

The amount of the substance transported through coating film from time t to t + dt is

$$dW_t = 2\pi RhF_{(t)}dt \qquad (7)$$

Integrating equation (7) from time 0 to t

$$W_t = \frac{2\pi R h \rho^{CT} S_0^{CT}}{\beta^{CT}} \frac{D_{CT}}{\ell}\left(1 - e^{-\beta^{CT} t}\right) \qquad (8)$$

C. Liquid Transport in Coated Concrete Cylinder

(a) Liquid transport without chemical reaction

For mass transport in cylindrical media, the second order differential equation is

$$\frac{\partial S}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r D_{CO} \frac{\partial S}{\partial r}\right) \qquad (9)$$

If the concentrate at the concrete surface is $\phi(t)$, the solution of the second order differential equation is

$$S = \frac{2D_{CO}}{R}\sum_{n=1}^{\infty} \exp\left(-D_{CO}\alpha_n^2 t\right)\frac{\alpha_n J_0(r\alpha_n)}{J_1(R\alpha_n)}\int_0^t \exp\left(D_{CO}\alpha_n^2 t\right)\phi(t)\,dt \qquad (10)$$

Assume the surface concentration is:

$$\phi(t) = S_o^{CO}\left\{1 - \exp\left(-\beta_1 t\right)\right\}$$

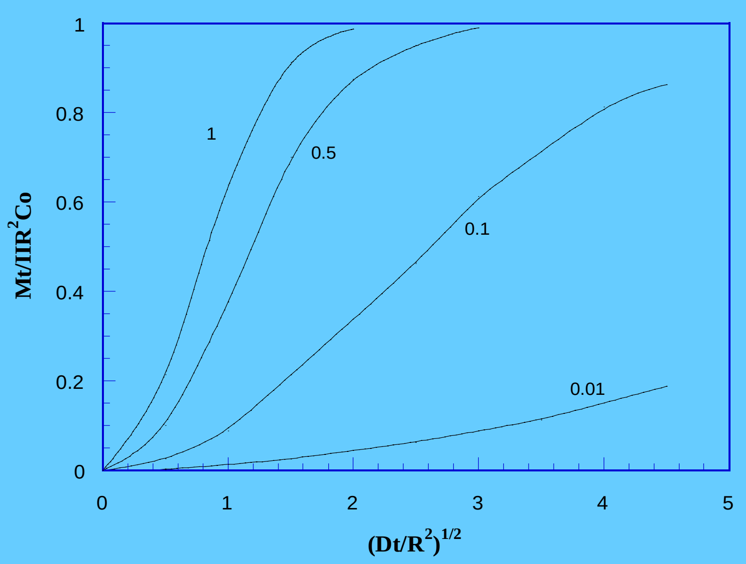
The solution of equation (10) is

$$\frac{S}{S_0^{CO}} = 1 - \frac{J_0\left\{\left(\bar{\beta} r^2 / D_{CO}\right)^{1/2}\right\}}{J_0\left\{\left(\bar{\beta} R^2 / D_{CO}\right)^{1/2}\right\}} \exp\left(-\bar{\beta} t\right) + \frac{2\bar{\beta}}{R D_{CO}} \sum_{n=1}^{\infty} \frac{J_0\left(r\alpha_n\right)}{\alpha_n J_1\left(R\alpha_n\right)} \frac{\exp\left(-D_{CO}\alpha_n^2 t\right)}{\left(\alpha_n^2 - \bar{\beta}/D_{CO}\right)} \qquad (11)$$

The sorption rate is

$$\frac{W_t^{CO}}{\pi R^2 \rho^{CO} S_0^{CO}} = 1 - \frac{2 J_1\left\{\left(\bar{\beta} r^2 / D_{CO}\right)^{1/2}\right\} \exp\left(-\bar{\beta} t\right)}{\left(\bar{\beta} R^2 / D_{CO}\right)^{1/2} J_0\left\{\left(\bar{\beta} R^2 / D_{CO}\right)^{1/2}\right\}} + \frac{4}{R^2} \sum_{n=1}^{\infty} \frac{\exp\left(-D_{CO}\alpha_n^2 t\right)}{\alpha_n^2 \left\{\alpha_n^2 / \left(\bar{\beta}/D_{CO}\right) - 1\right\}} \qquad (12)$$

Calculated Sorption Curves from equation (12)
Numbers on Curves Are
Values of $\bar{\beta} R^2 / D_{CO}$



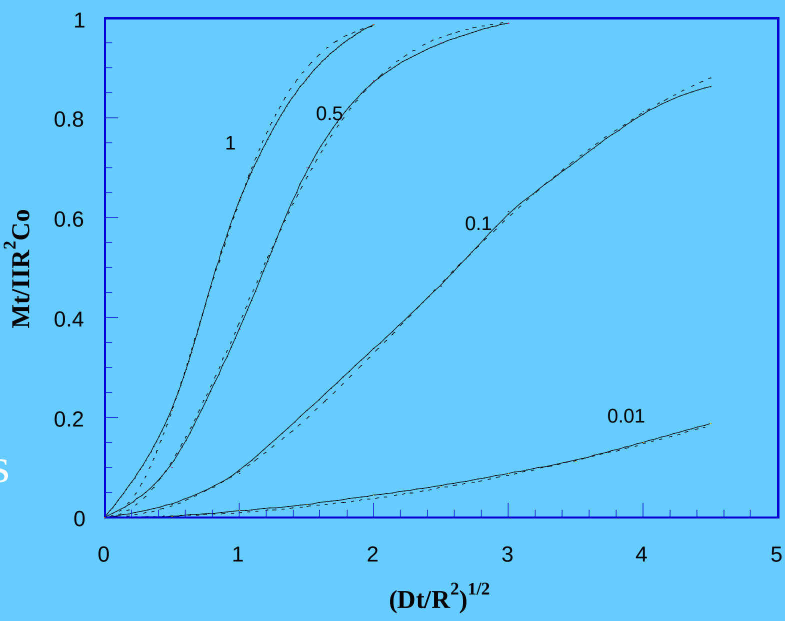
Define $\lambda_{CO} = \bar{\beta} R^2 / D_{CO}$

Approximating this relationship and considering an exponential function of the form

$$\frac{W_t^{CO}}{\pi R^2 \rho^{CO} S_0^{CO}} = \left\{ 1 - \exp\left[-\lambda_{CO} \left(\frac{D_{CO} t}{R^2} \right)^n \right] \right\} \quad (13)$$

Values of Parameter n from Curve Fitting

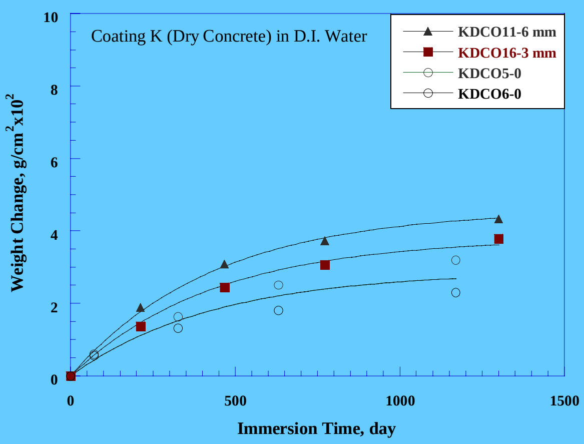
λ_{co}	n	R
0.01	1.006	0.999
0.1	1.009	0.999
0.5	1.042	0.999
1	1.001	0.999
5	1.346	0.999

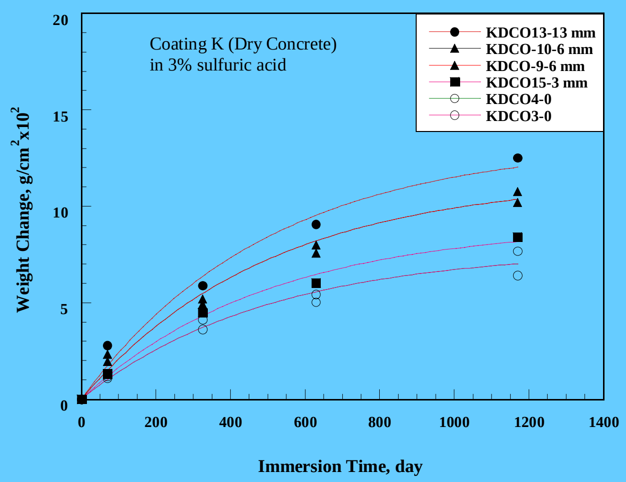


Comparison of standard curves and approximate solution

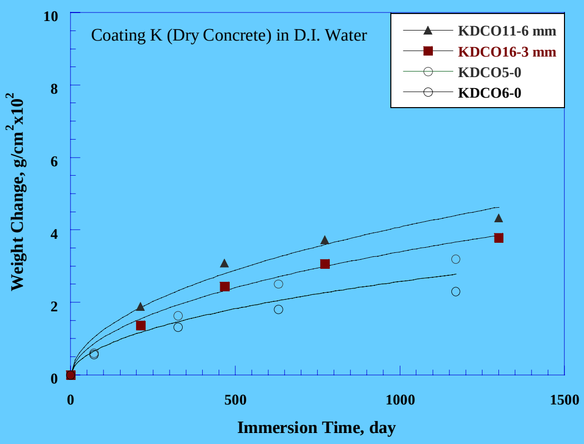
D. Verifications of Mass Transport Models

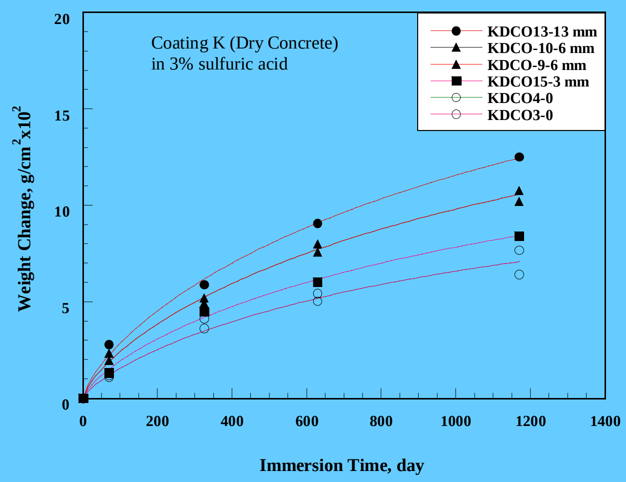
Film Model





Concrete Models





3. Calcium Leaching

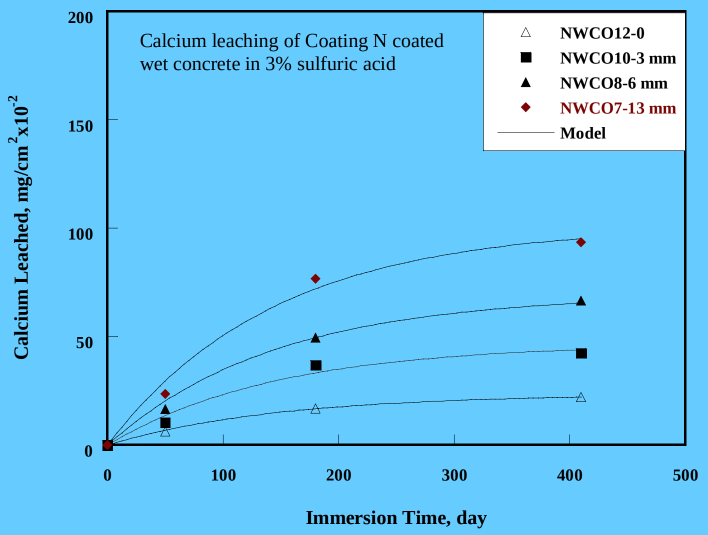
Assume the rate of calcium leaching from coated concrete is of the first order kinetic of the total calcium leached (C_s)

$$\frac{dC_s}{dt} = \alpha(kM_c - C_s) \qquad (17)$$

Integrating Equation (17) at $t = 0, C_s = 0$ and $t = t, C_s = C_s$

$$C_s = \pi R^2 hkC_f(1 - e^{-\alpha t}) \qquad (18)$$

The effect of pinhole sizes can be corrected by equation (16)



CONCLUSIONS

Based on the experimental results, the following observations are advanced

(1) **Hydrostatic Test:** used to evaluate the applicability of coatings onto concrete under hydrostatic back pressure with a moisture emission of 536 mg/(s.m2) (9.49 lb/(1000ft2.24h)). Many coatings tested in the study were successfully applied on to the concrete surface. Some coating developed blisters during the testing period.

(2) **Chemical Test:** coated concrete specimens with pinholes failed sooner than without pinholes and the time to failure depended on the type of coating and pinhole size. Based on time-to-failure analysis, the selected coatings can prolong the service life of concrete by 14 and 57 times without failure. Testing coated concrete specimens with pinholes is considered to represent the critical condition in the field.

(3) **Bonding Test:** There was no direct correlation between bonding strength and chemical resistance of coated concrete.

(4) Although coatings can be of the same base material the performance can be totally different.

Protocols and Test Plans

- Verification Protocol for the Verification of Grouting Materials for Infrastructure Rehabilitation at the University of Houston - CIGMAT (September 2004)
- Generic Verification Protocol for Secondary Effluent and Water Reuse Disinfection Applications (October 2002)
- Protocol for the Verification of Chemically Enhanced High-Rate Separation (May 2000)
- Protocol for the Verification of Flowmeters for Wet Weather Flow Applications in Small - and Medium-Sized Sewers (September 2000)
- Protocol for the Verification of High-Rate Wet Weather Flow Disinfection Applications (July 2000)

Testing Composite Coating Systems with Silanes for Protecting Concrete Columns on the Galveston Causeway Project

by

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DOCUMENTS REVIEWED

1. **NCHRP Report 244:**

   Concrete Sealers for Protection of Bridge Structures

2. **Florida Dot Standard:**

   Specifications for Road and Bridge Construction

   Section 413: Sealing Concrete Structure Surfaces

3. **Texas DOT Material Specifications**

   Section 5. DMS-8110, Coatings for Concrete

   Section 9. DMS-8140, Concrete Surface Treatment (Penetrating)

CIGMAT Test Programs

1. Immersion Test (NCHRPR 244) (including Ca^{2+} Leaching) (CIGMAT CT-1)

2. Bonding Test (ASTM D 4541/CIGMAT CT-2)

3. Thermo Cycling Test (Long-term Durability)

4. Permeability Test (AASHTO T277-89)

OBJECTIVES

(1) Evaluate the effectiveness of Silanes in reducing the chloride (NaCl) infiltration (Immersion Test)

(2) Effect of Silanes on the performance of Latex Paints (Infiltration and Bonding)

(3) Long-term performance of Latex paints under temperature cycling.

(4) Chloride permeability of the uncoated and coated concrete

MATERIALS

Concrete

TxDOT Class F. (concrete specimens were cured for 28 days)

Silane

Silane 1

Silane 2

Coatings/ Latex Paint

Coating 1

Coating 2

TESTING PROCEDURES

Concrete Specimen Preparation

(1) Water blasting at 1500 psi to remove loose material on the surface;

(2) Drying for 2 days at room condition (23 ± 2 ^{o}C, 50 ± 5% RH);

(3) Applying Silane on concrete at 25 psi;

(4) Drying specimens for 7 days;

(5) Applying Latex on Silane coated concrete and uncoated concrete;

(6) Curing specimens for 4 days (room condition).

Immersion Test (Cylindrical Specimens)

1) Cylindrical specimens were immersed in tap water and 15% NaCl solution for 21 days;
2) Dry the specimens for 21 days;
3) In order to study pinhole effects on water and salt penetration, 1/8" pinholes were intentionally made on some of the specimens.

Bonding Test

1) The ASTM D 4541 test method was used to determine the bonding strength of Latex to concrete with/without Silane;
2) Prism specimens were coated in the same manner as the specimens for the immersion test;
3) The specimens were cured in the room condition, tap water and 15% NaCl solution;
4) Bonding strength was determined at the beginning and end of the immersion test.

Temperature Cycling Test

1) Temperature cycling test was performed on specimens coated with Sliane & Latex and Latex only;

2) The maximum temperature was 120 ^{o}F;

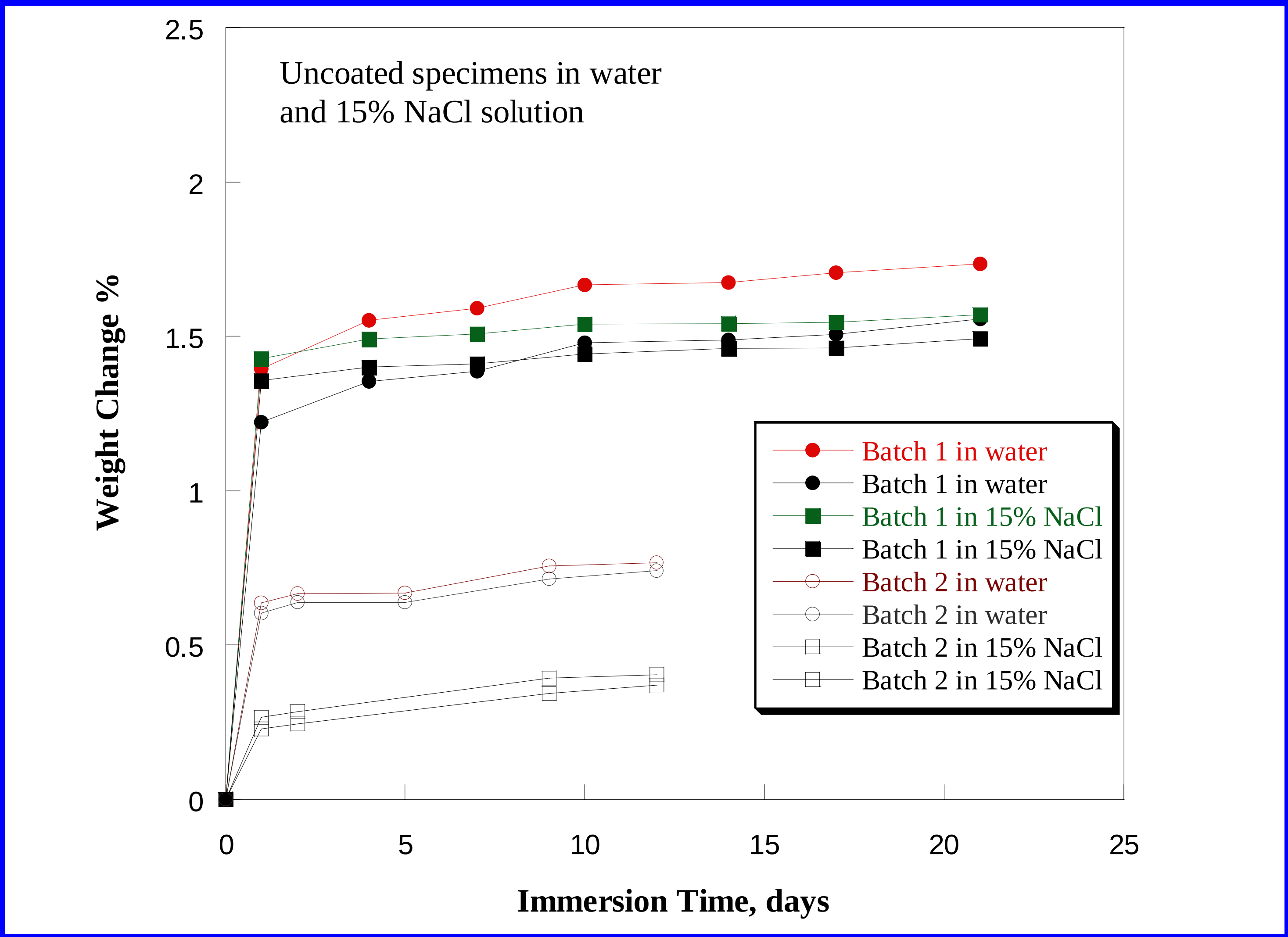
3) The specimens were at 120 ^{o}F for 3 days and at room condition for 1 day, then immersed in 15% NaCl for 3 days. Repeat the process.

4) Cylindrical specimens were used for the thermal cycle test.

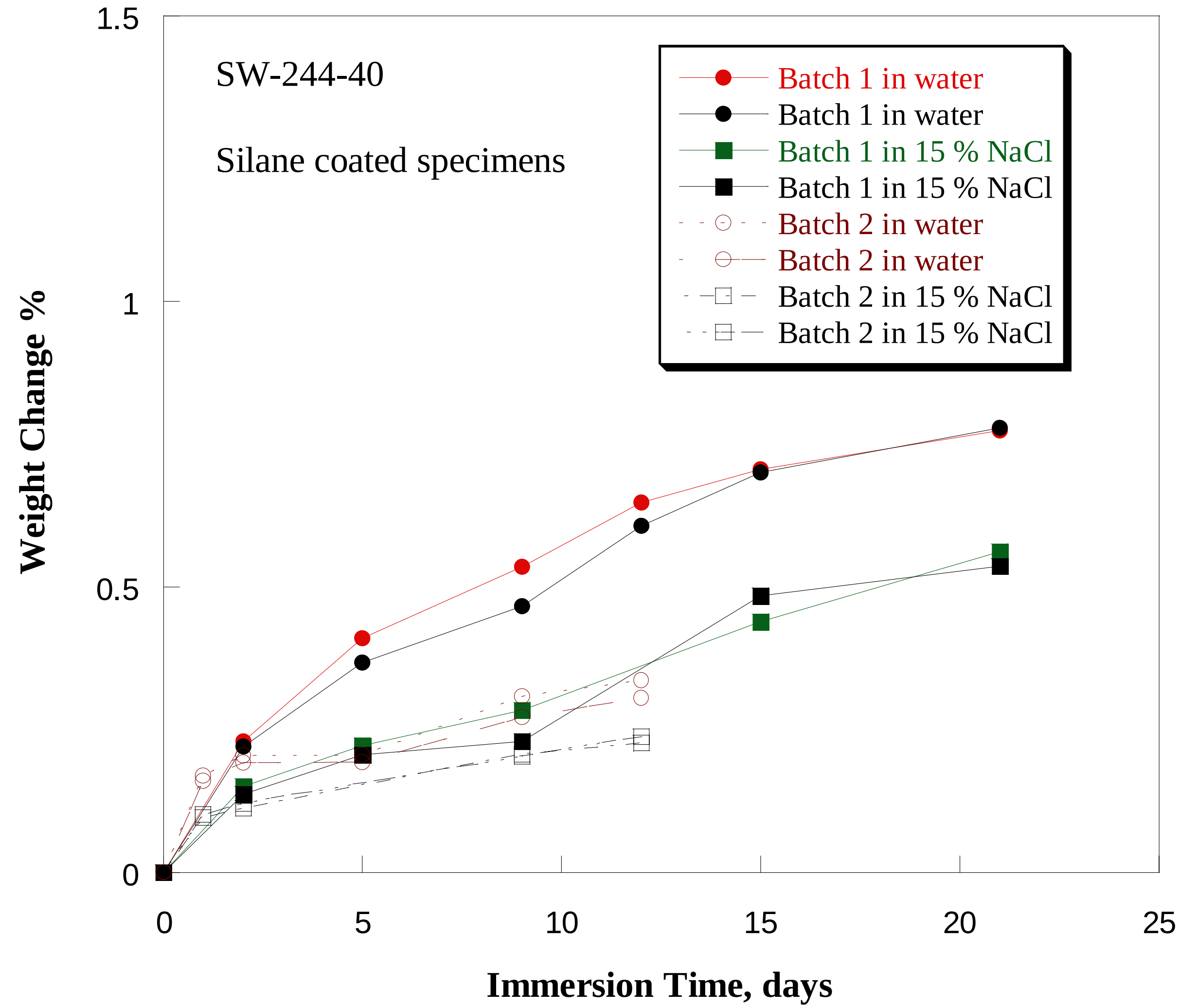
Comparison of Batch 1 and Batch 2 Concrete

Batch	Average Weight of Specimens (g)	Density (lb/ft^3)	Density (kg/m^3)
1	1559.36	140.16	2247.2
2	1636.21	147.07	2358.0

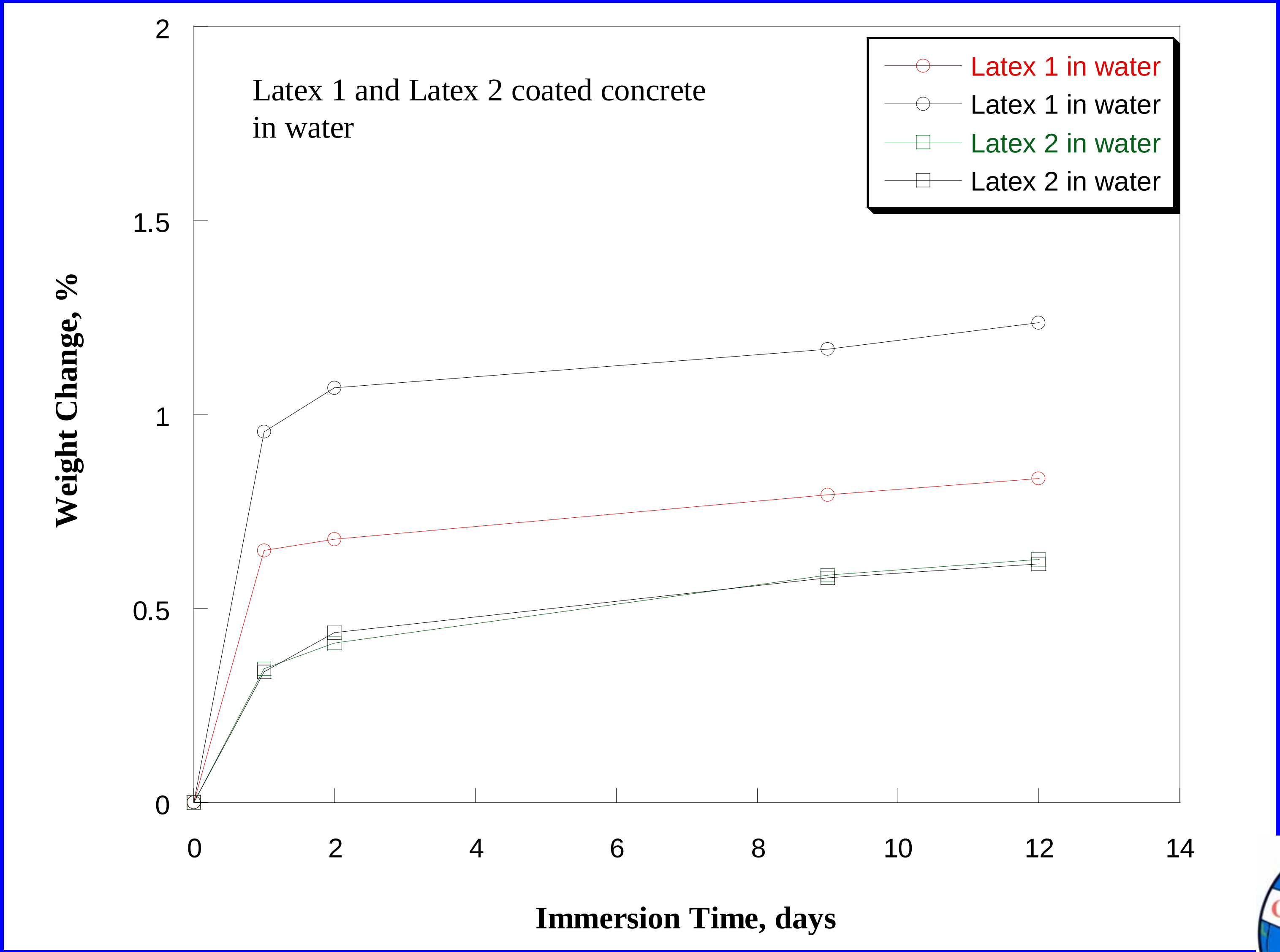
Comparison of Batch 1 and Batch 2 Concrete in Water and 15% NaCL



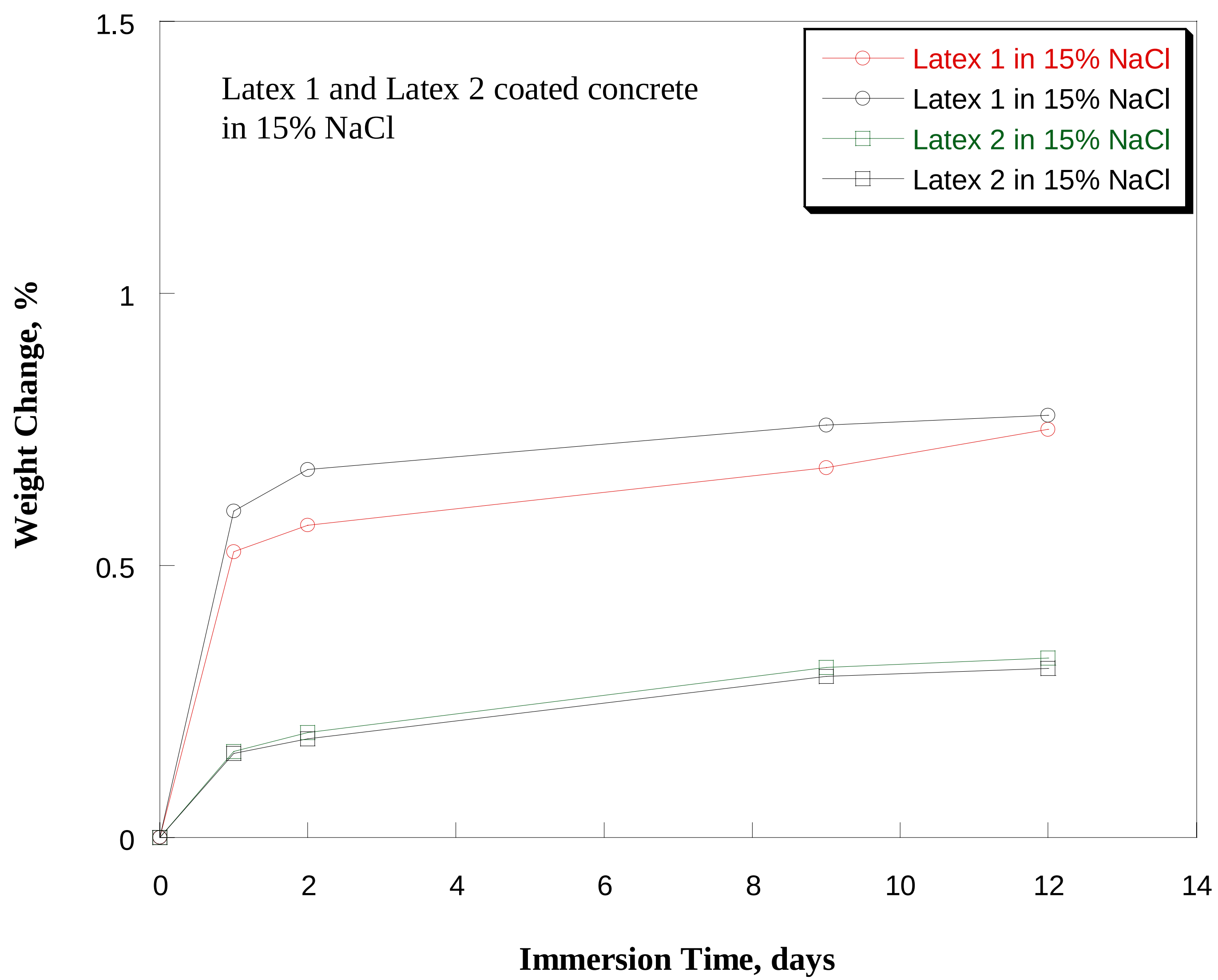
Silane Coated Concrete in Water and 15% NaCl Solution



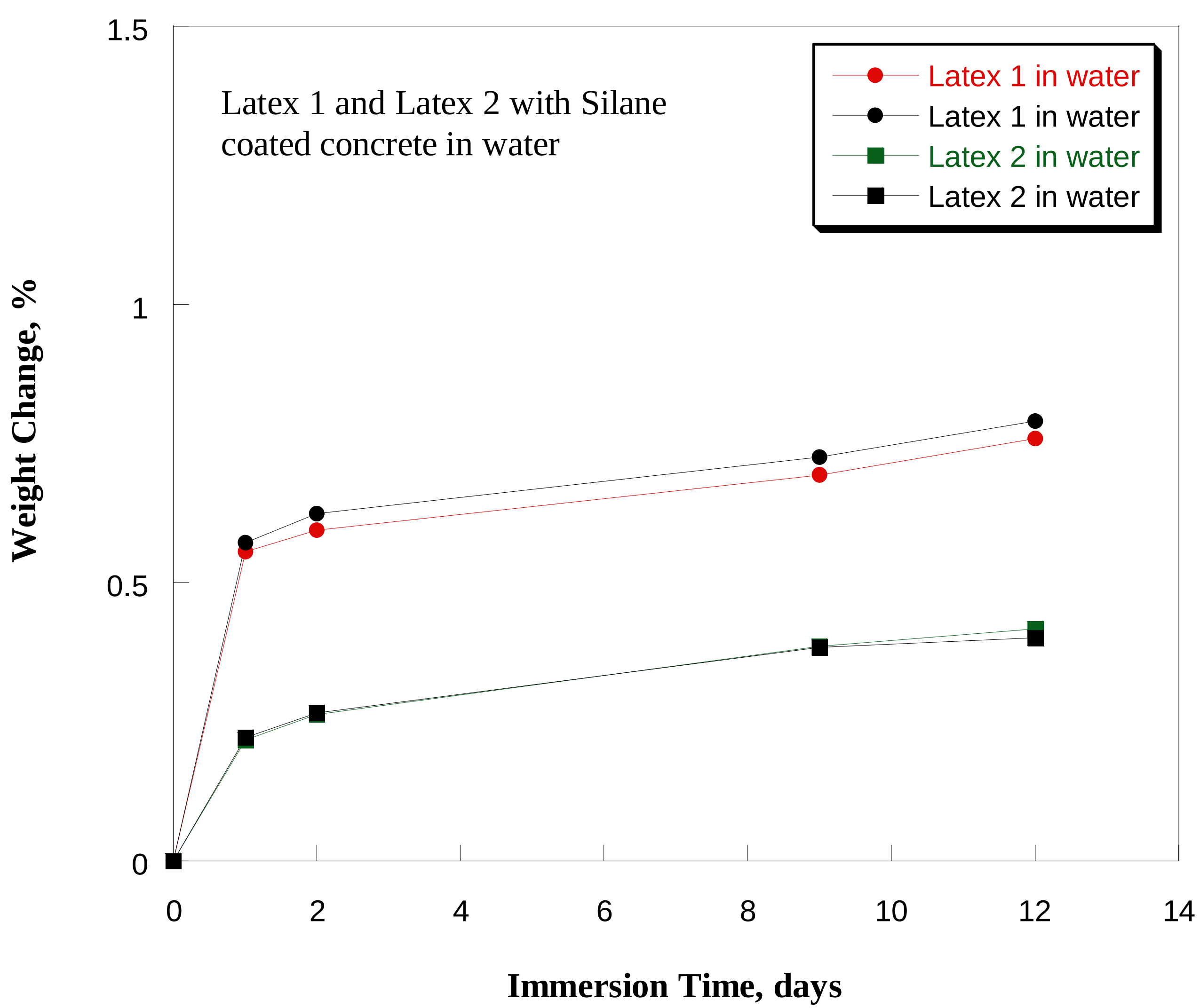
Coating-1 & -2 Coated Concrete in Water – Batch 2 Concrete



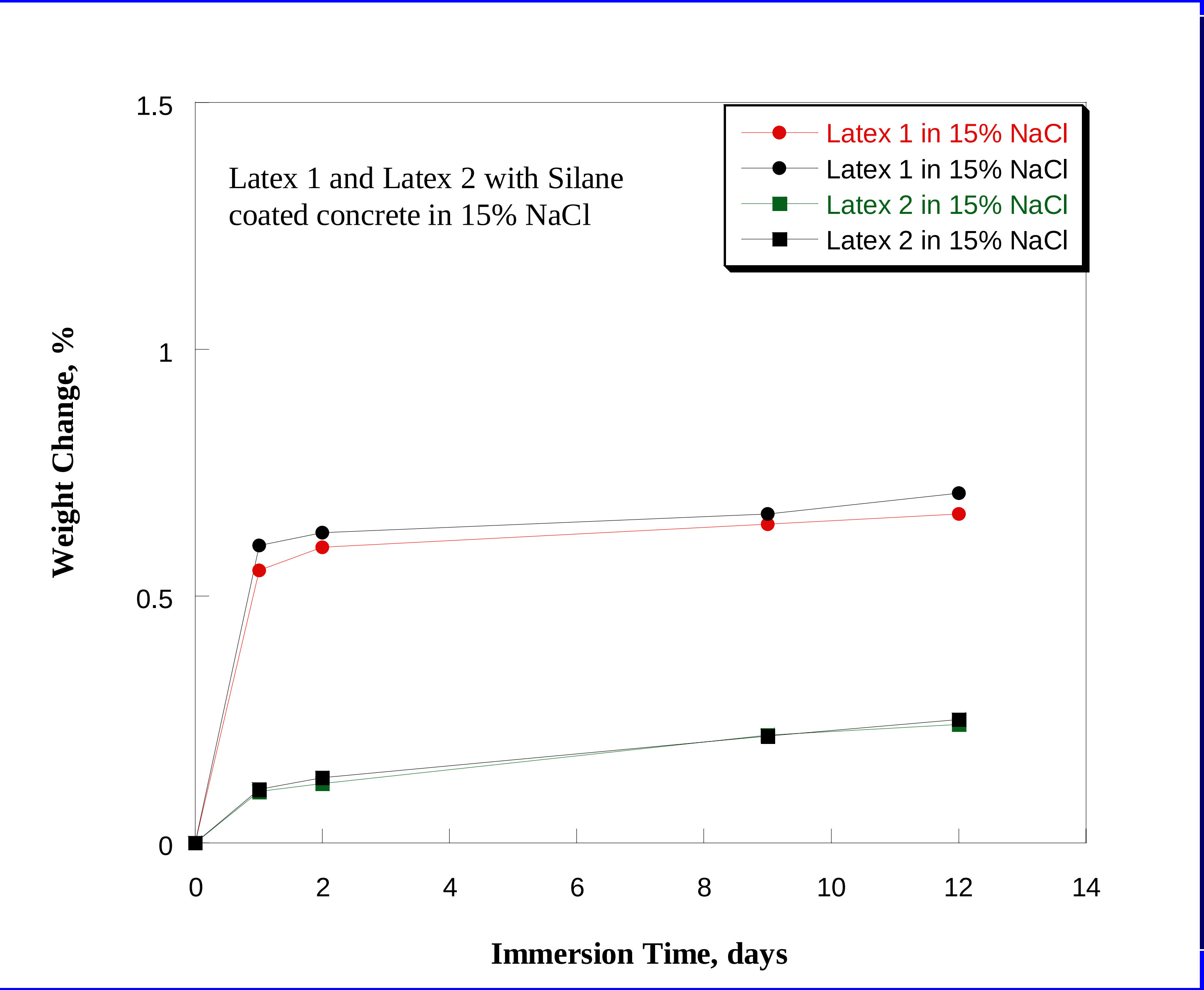
Latex 1 and Latex 2 Coated Concrete in 15% NaCl – Batch 2 Concrete



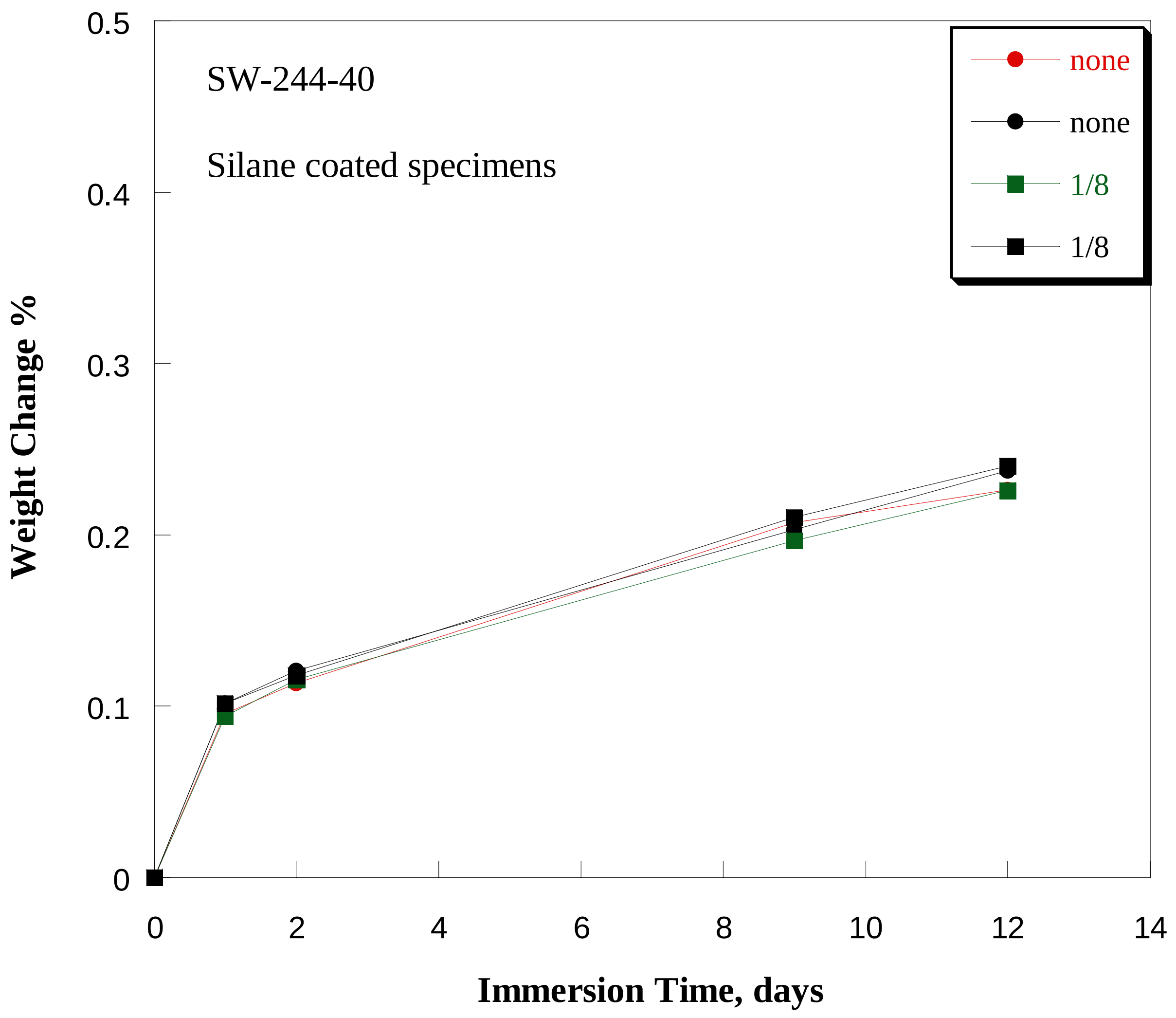
Latex-1, Latex-2 and Silane Coated Concrete in Water – Batch 2 Concrete



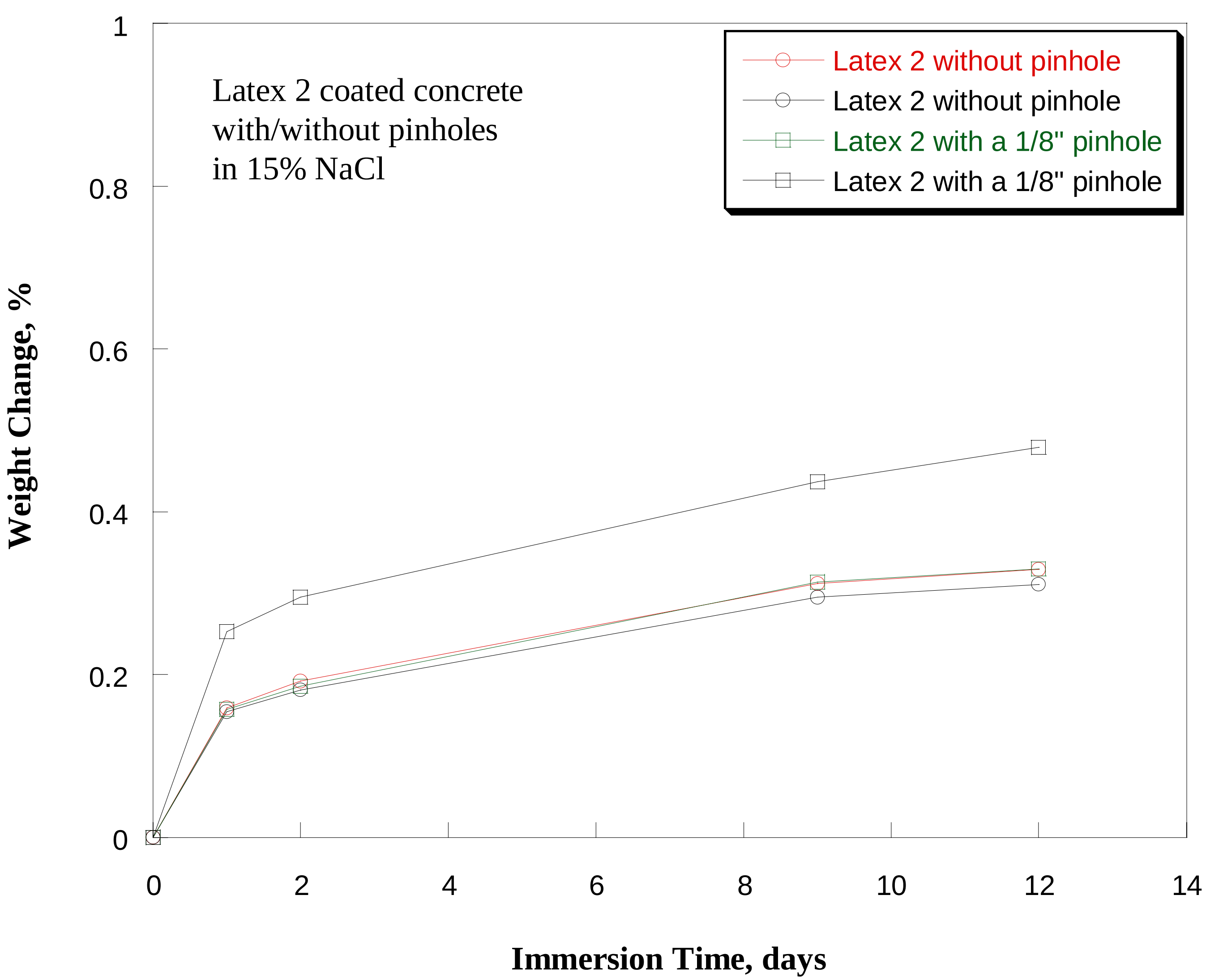
Latex-1, Latex-2 and Silane Coated Concrete in 15% NaCl – Batch 2 Concrete



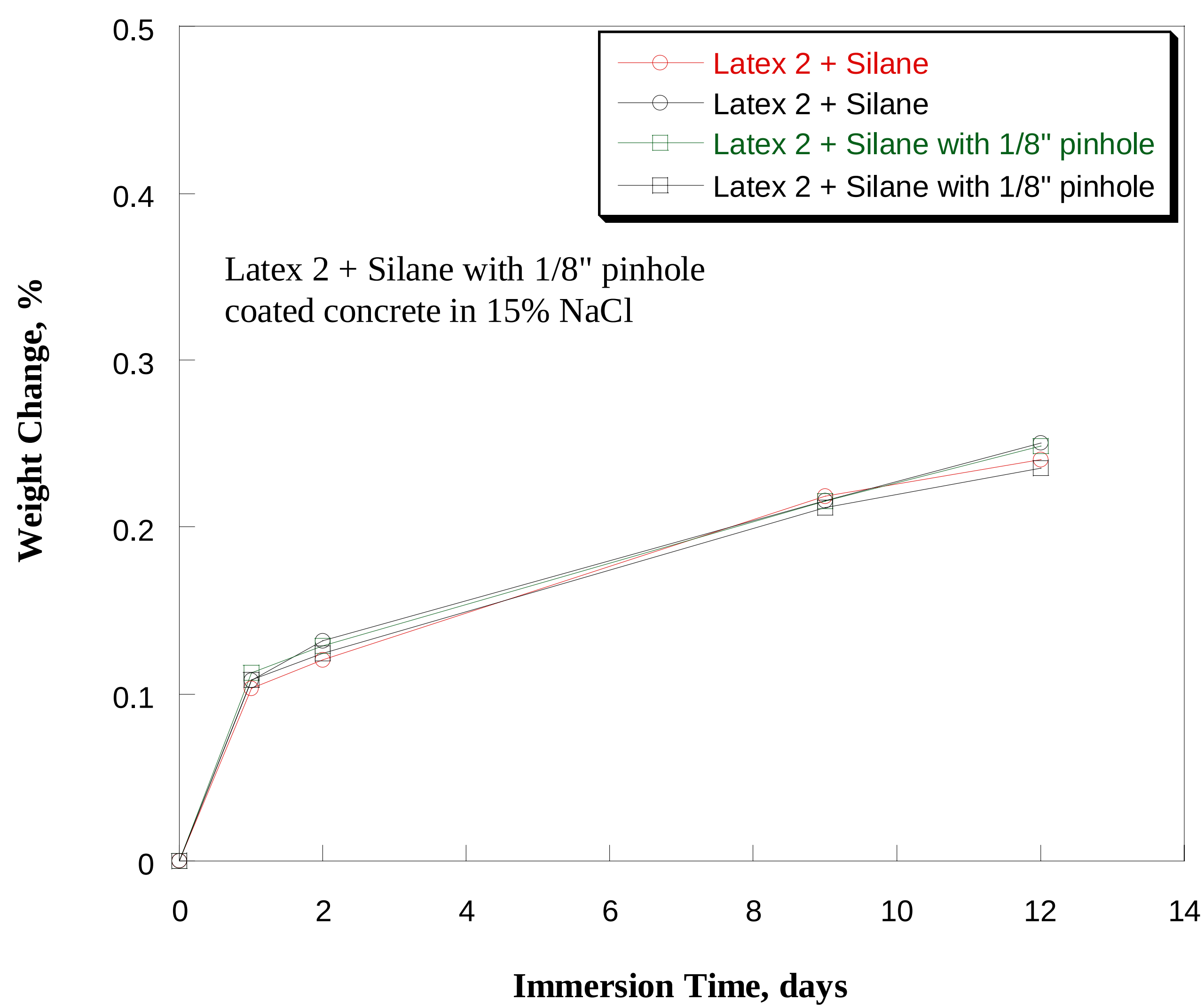
Silane Coated Concrete with/without Pinhole in 15% NaCl – Batch 2 Concrete



Latex-2 Coated Concrete with/without Pinhole in 15% NaCl – Batch 2 Concrete



Latex-2 and Silane Coated Concrete with/without Pinhole in 15% NaCl – Batch 2 Concrete



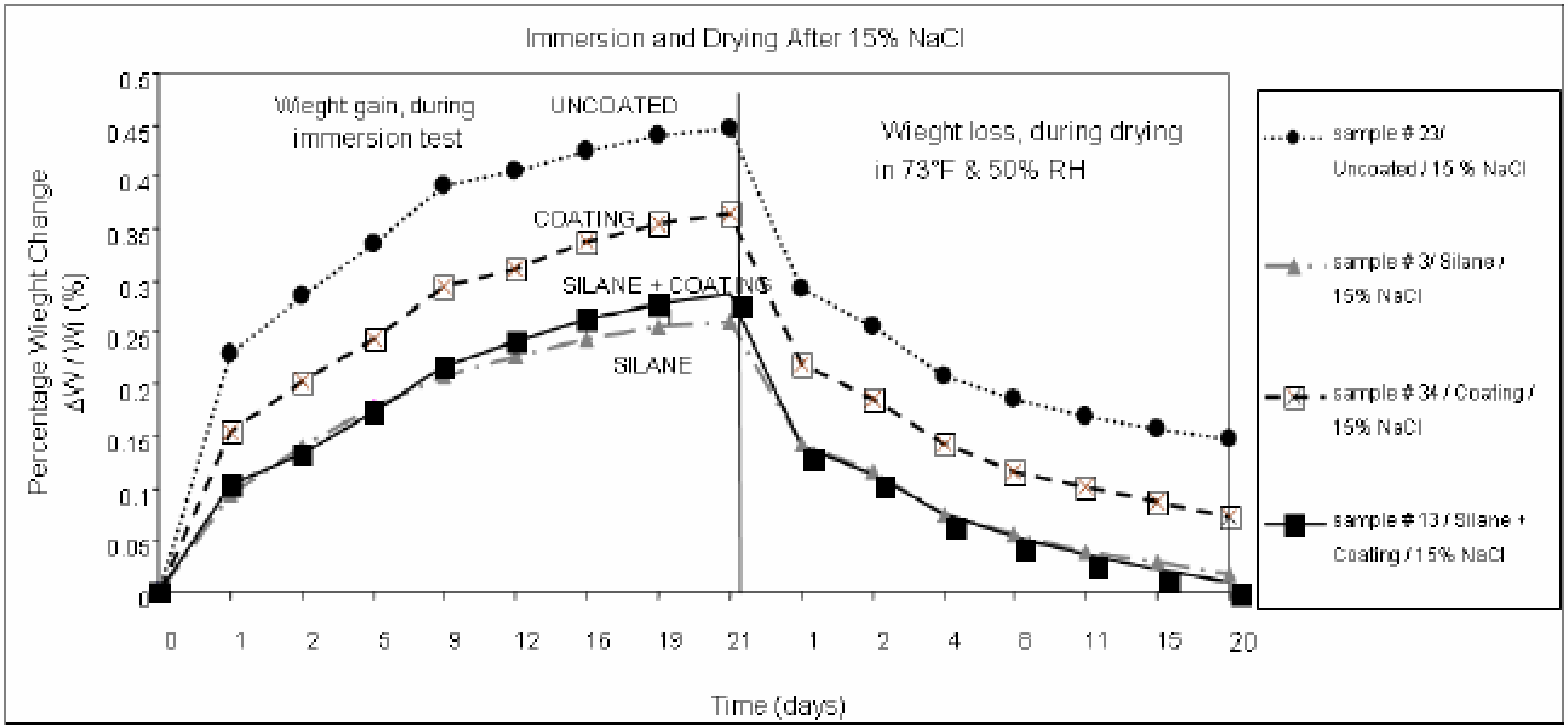
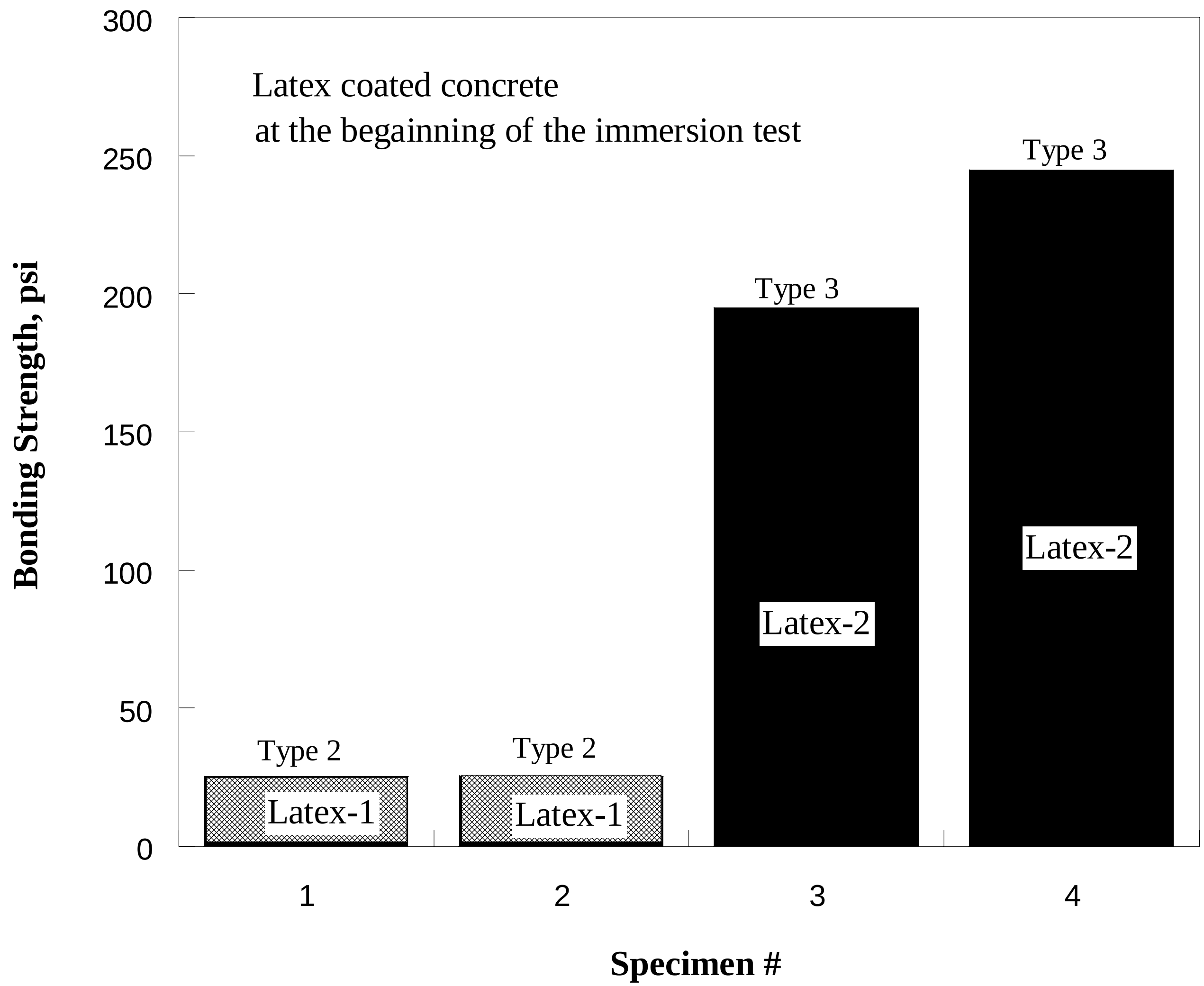


Figure 9.6 Residual weight changes after immersion of specimens (silane, coated concrete, silane + coated concrete in 15% NaCl solutions.

Latex-1 and Latex-2 Coated Concrete

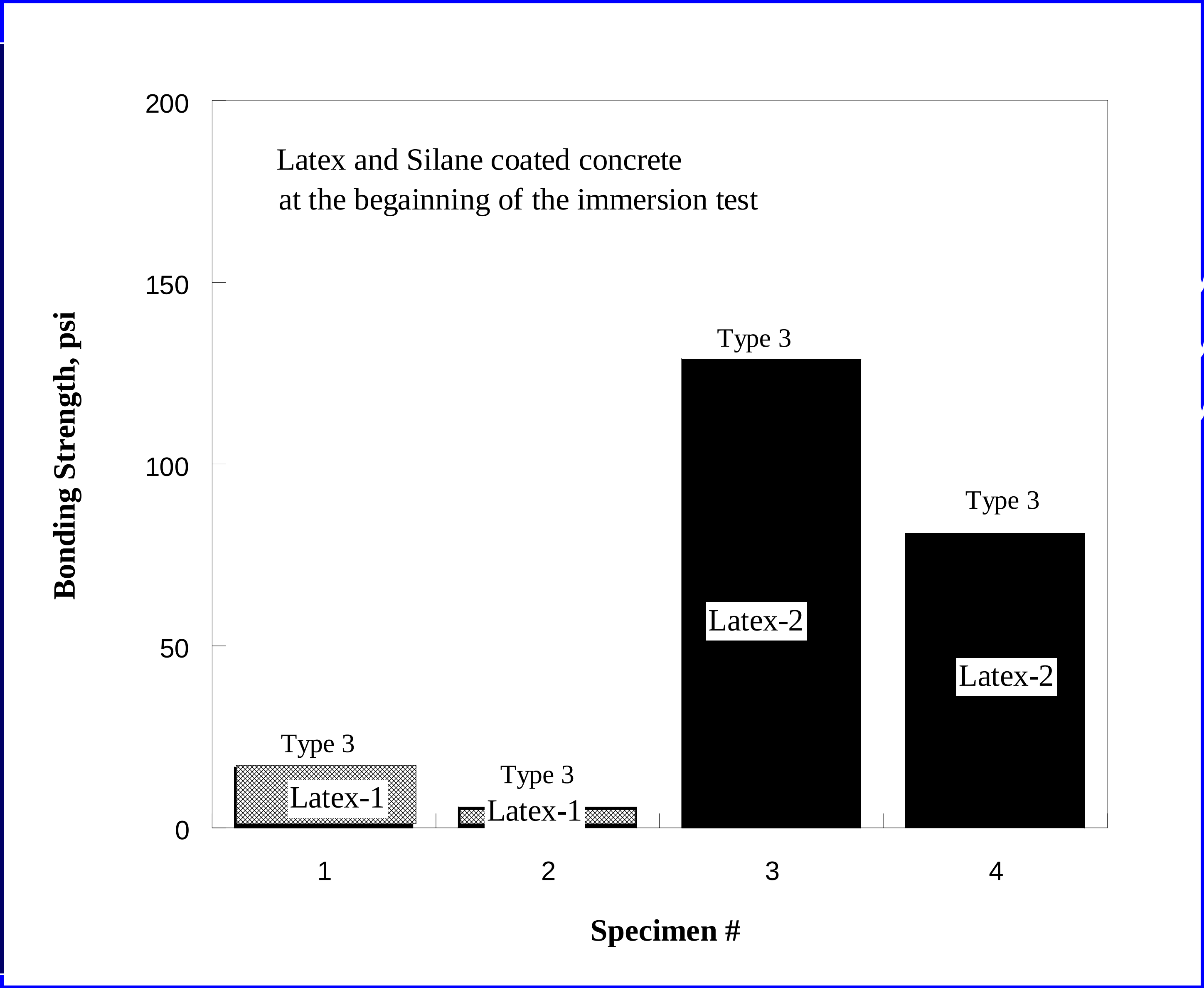


pe 1 Concrete Failure

pe 2 Latex Failure

pe 3 Bonding Failure

Latex-1, Latex-2 and Silane Coated Concrete



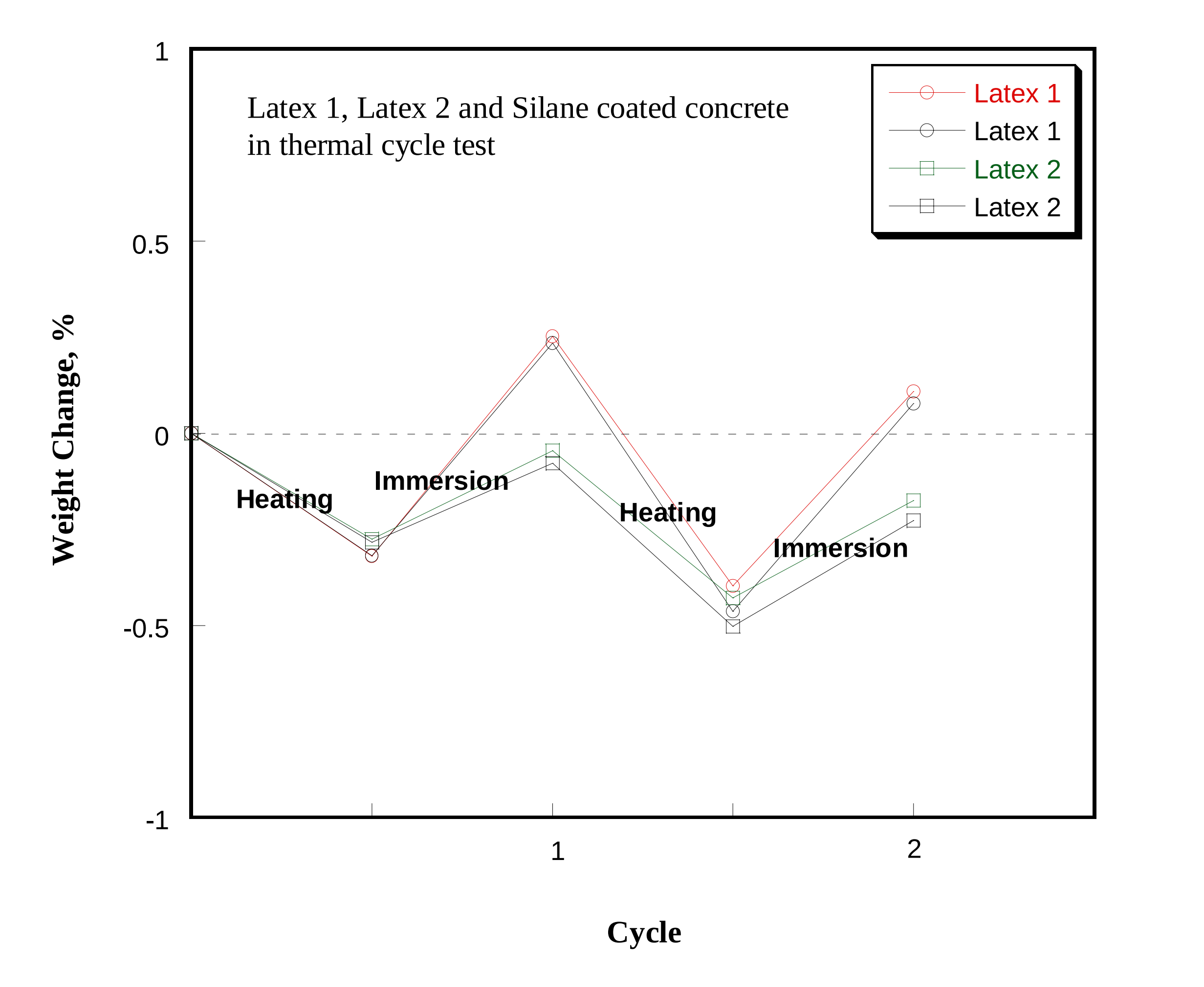
ype 1 Concrete Failure

ype 2 Latex Failure

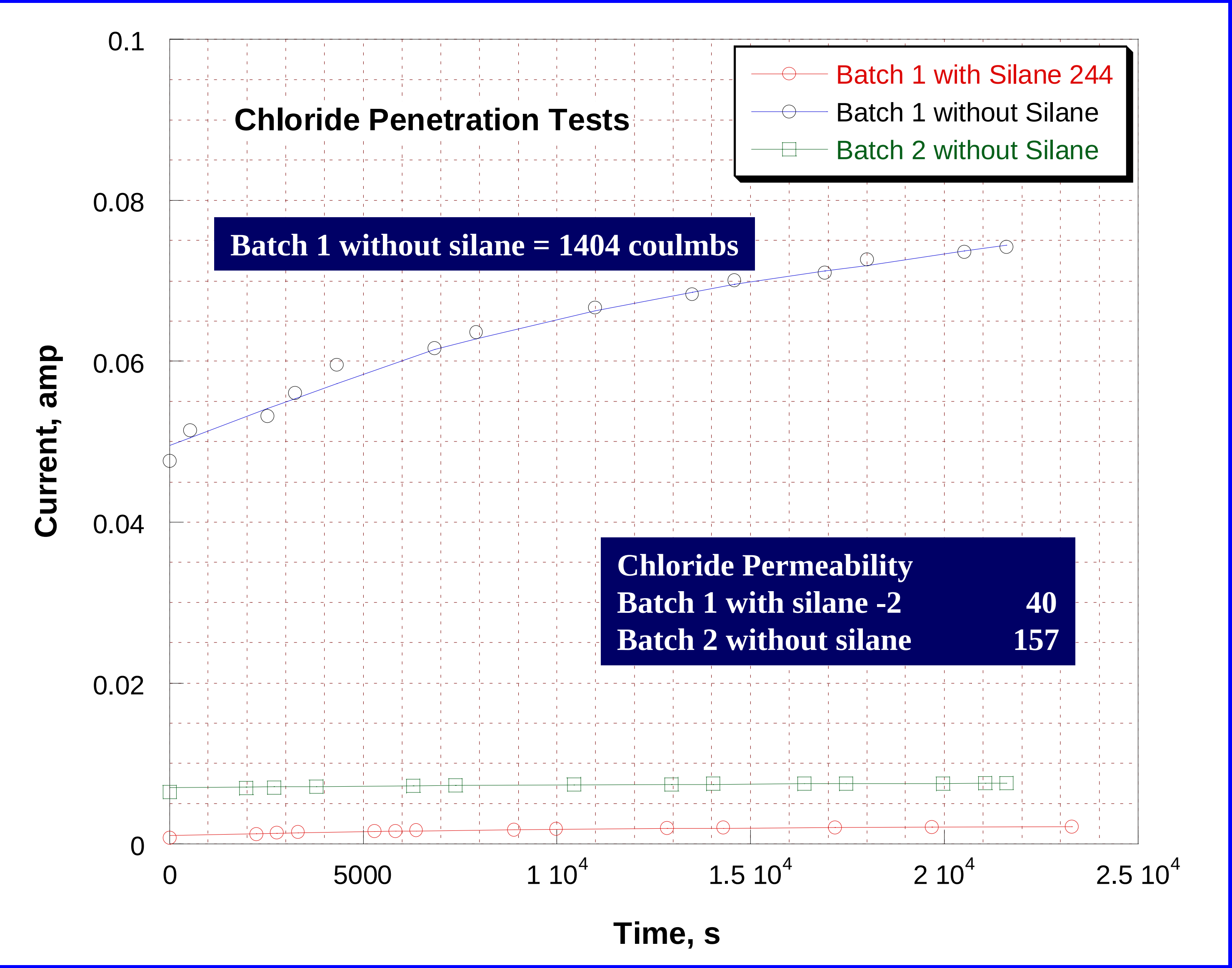
ype 3 Bonding Failure

Temperature Cycling Test

The thermal cycle test is on going.



Chloride Penetration Test Results



Chloride Permeability (AASHTO)

TABLE 1 Chloride Permeability Based on Charge Passed (from Reference 2)

Charge Passed (coulombs)	Chloride Permeability	Typical of—
>4,000	High	High water-cement ratio, conventional (>0.6) PCC
2,000-4,000	Moderate	Moderate water-cement ratio, conventional (0.4-0.5) PCC
1,000-2,000	Low	Low water-cement ratio, conventional (<0.4) PCC
100-1,000	Very Low	Latex-modified concrete Internally sealed concrete
<100	Negligible	Polymer impregnated concrete Polymer concrete

[2] Whiting, D., "Rapid Determination of the Chloride Permeability of Concrete," Report No. FHWA/RD-81/119, August 1981, available from NTIS, PB No. 82140724.

CONCLUSIONS

(1) Latex-2 is showed better bonding strength with concrete than Latex-1.

(2) Silane-2 (SW 244-20) reduced the bonding strength between Latex-2 and concrete.

(3) Immersion, Thermo-cycling and Bonding Tests with Silane -2 and Latex-2 were Acceptable.

(4) Chloride Permeability Test Results were Acceptable.