Performance Evaluation of Silane in Concrete Bridge Decks Using Transmission X-ray Microscopy

Amir Behravan, *Syed Muhammad Aqib , Norbert J. Delatte , M. Tyler Ley, Anna Rywelski*

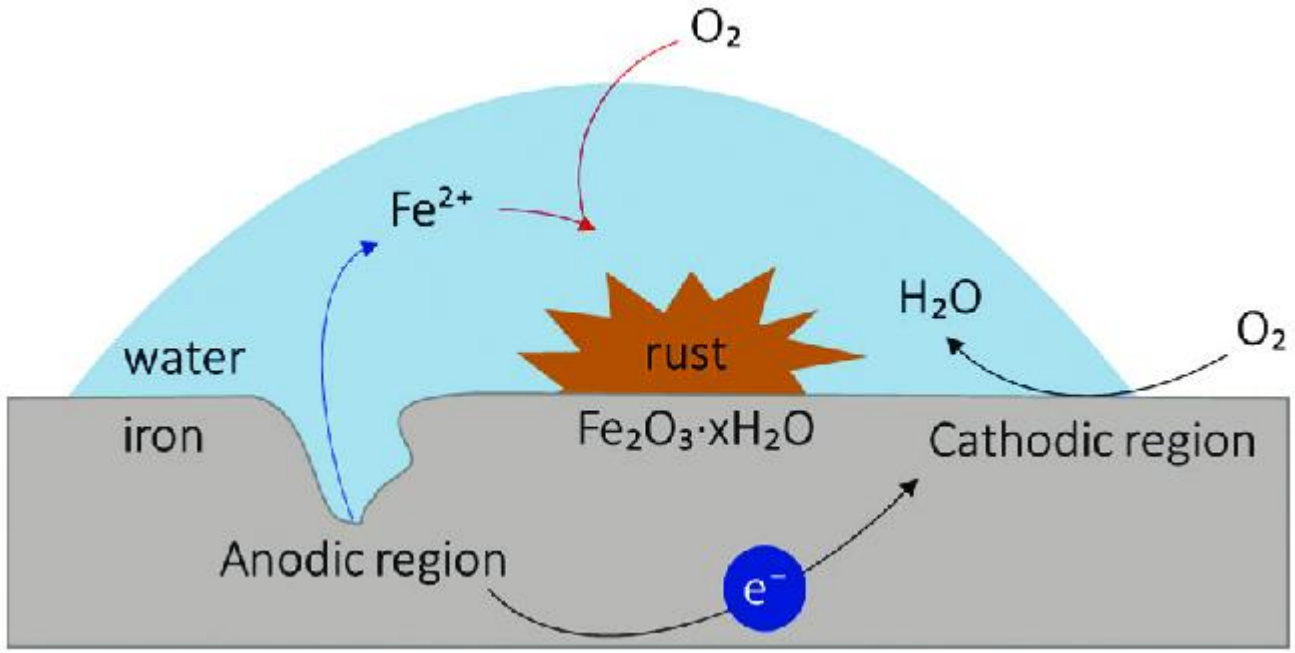
Amir.behravan@vdot.virginia.gov

The Durability of concrete:
The resistance to internal and external deteriorating influences.

The majority of concrete structures fail because of lack in durability performance not strength performance.

An important deteriorating factor is…

Corrosion

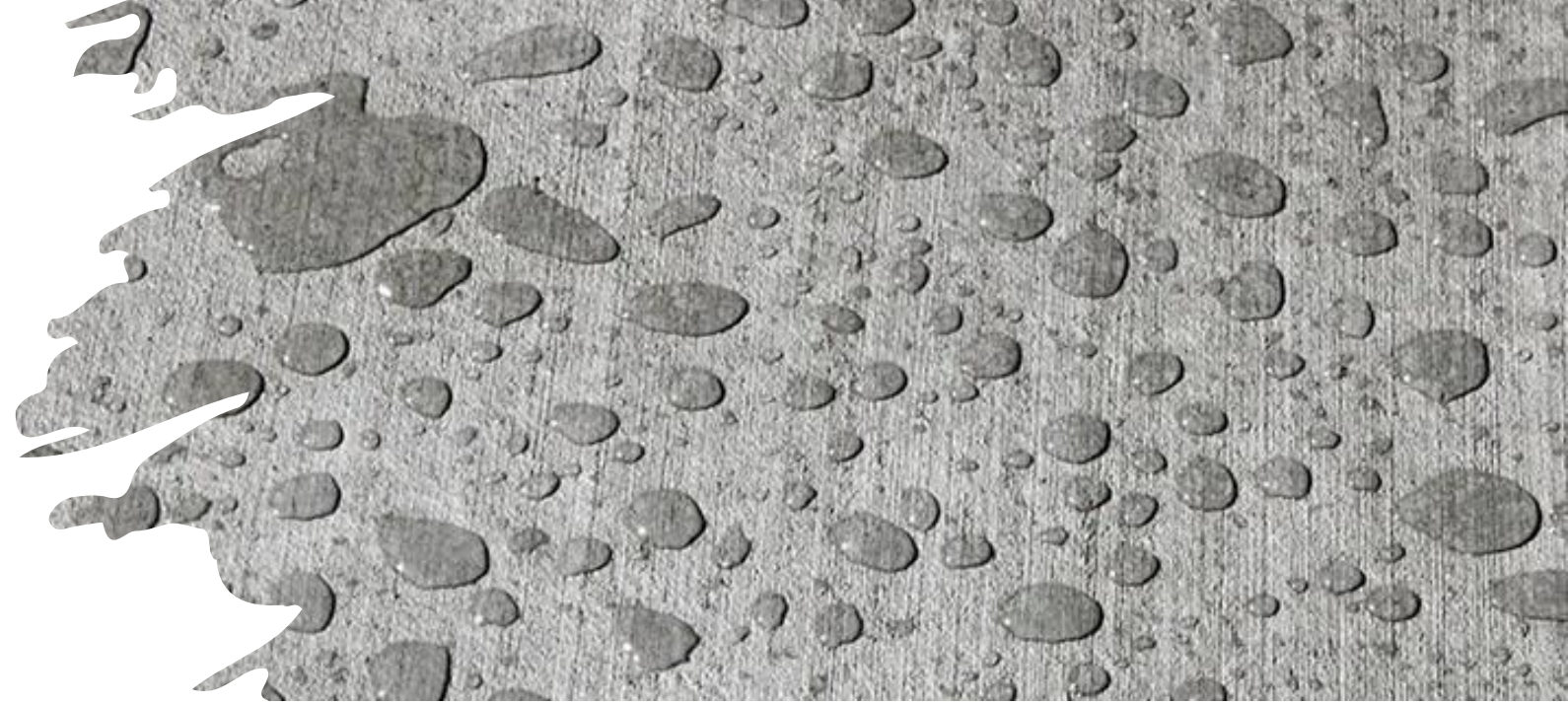


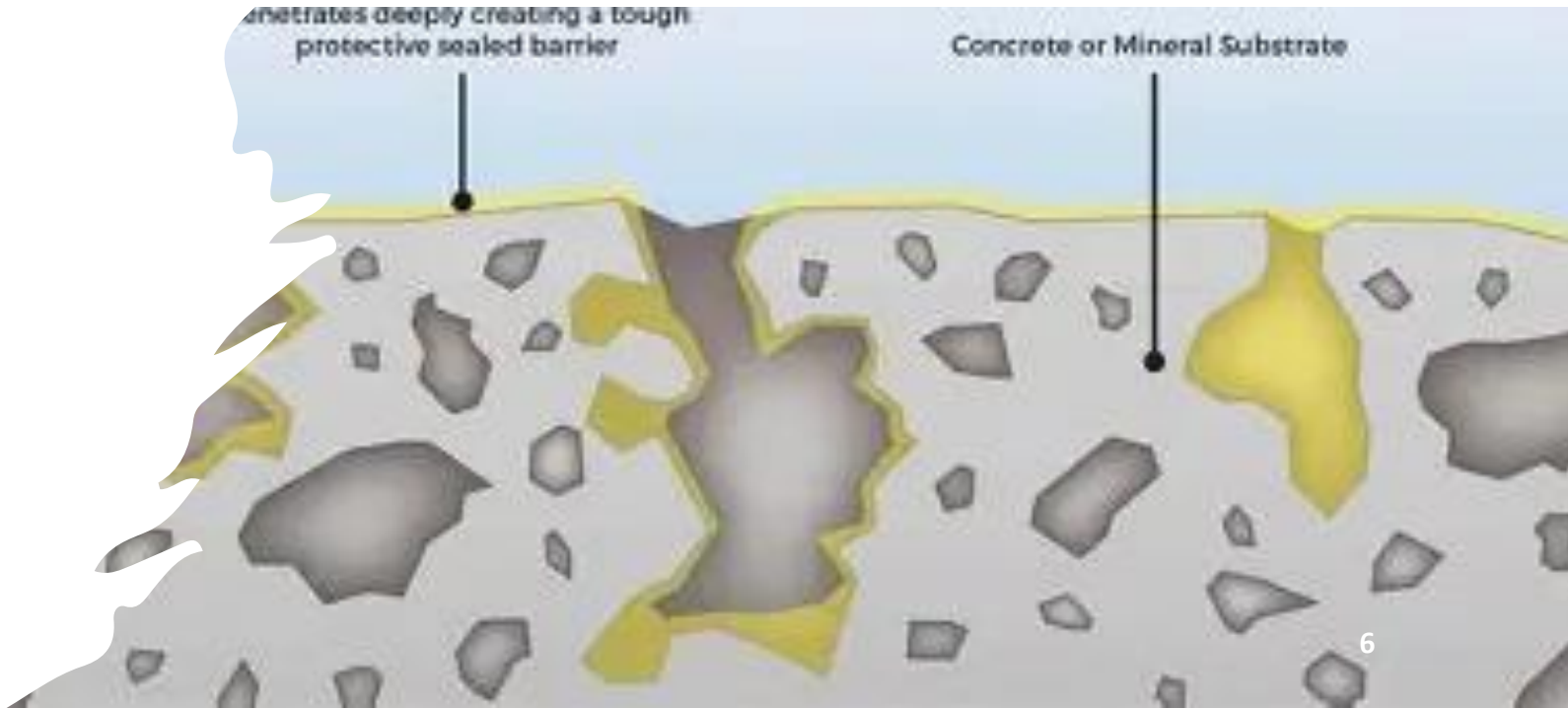
- **Steel + Moisture + oxygen → Rust**
- **Expansion of rust → Cracks and structural damage**

Solution?

Many options;

Sealers application





Silane

- Si-C bonds → Hydrophobic lining
- Effective for reducing ingress of external fluids
- **Varied/nonconclusive results**
  - No standard test method for evaluation

- **The Oklahoma Department of Transportation (ODOT) has been using silane treatments to reduce the permeability of the bridge deck concrete for over 40 years.**

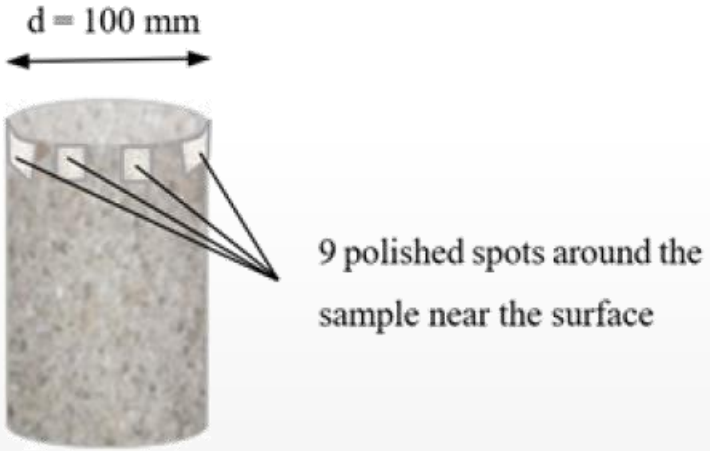
Problem?

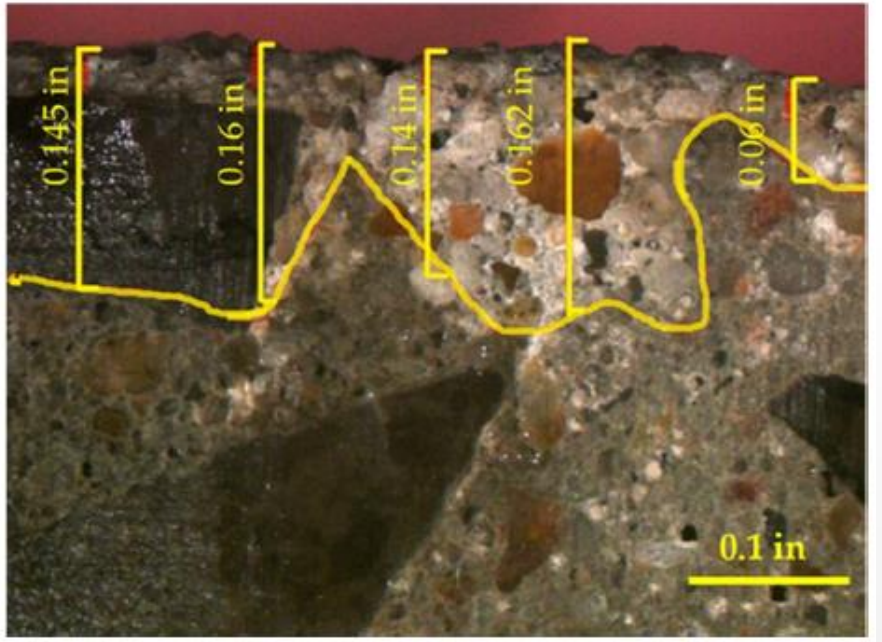
- **The evaluations of the silane coatings on bridge decks conducted by ODOT showed that the coatings are showing variable performance depending on the contractor that applied them.**

Samples

- **Cores from 14 bridge decks (1 year in service)**
  - No external environmental stresses (i.e. sulfate/chloride attacks)
- **4” in diameter**
- **W/CM = .41-.44**
- **Half 20% Class C fly ash, half only Portland cement**

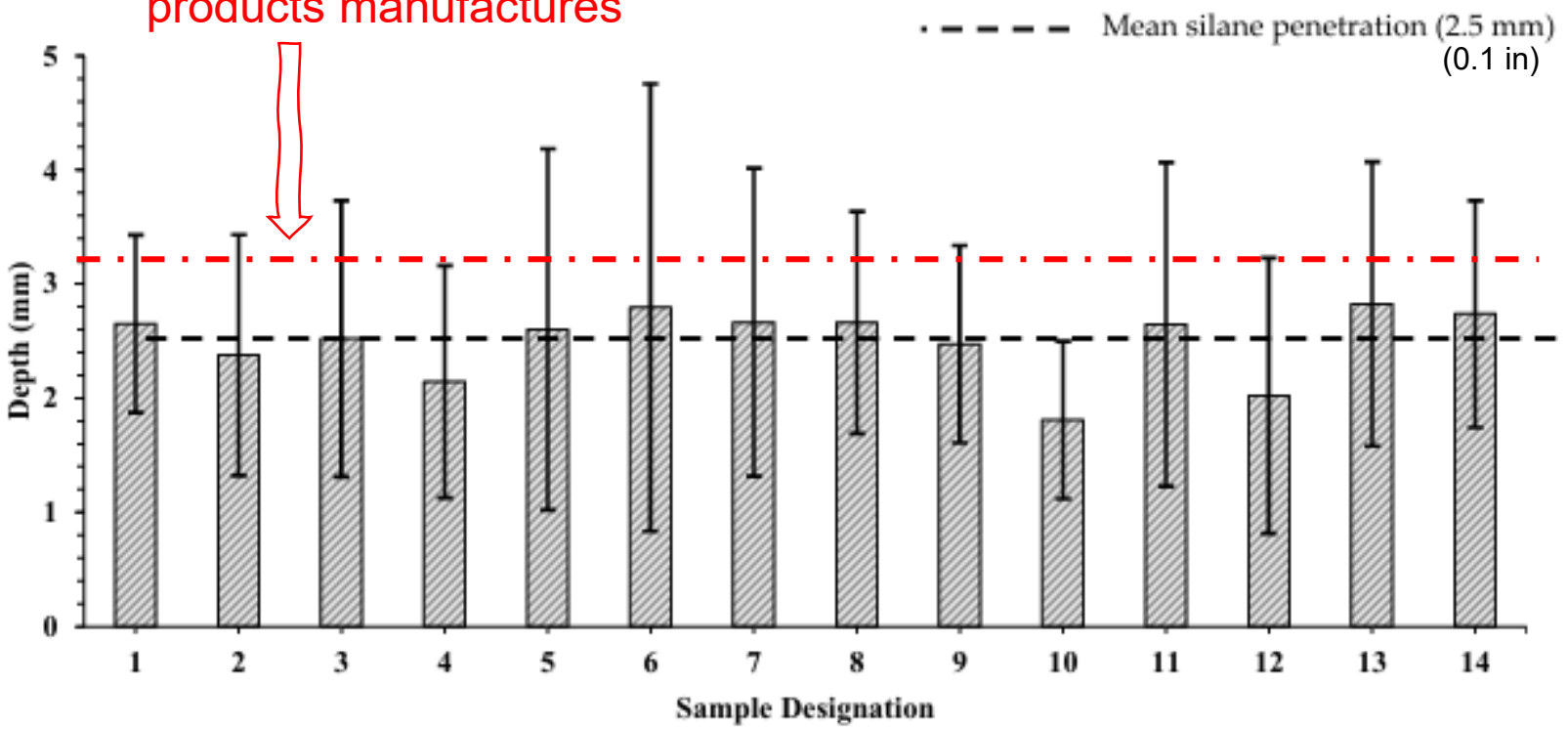
Silane Penetration Depth





45 Measurements / Core

Required by some specifications or products manufactures



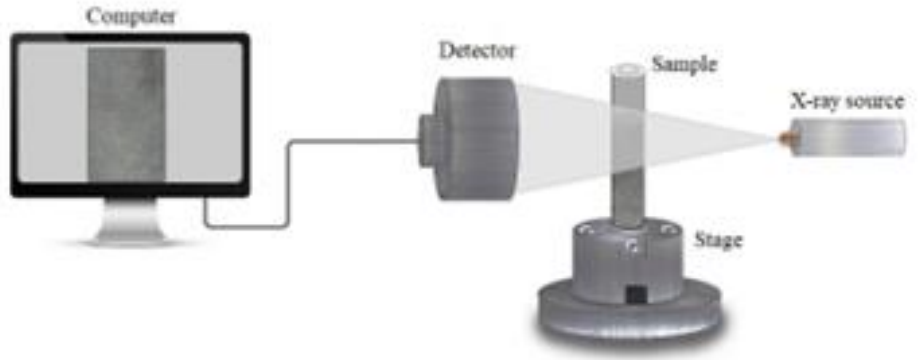
Question 1:

- **Is Silane Still Effective When Penetration Depth Is Below the Required Limit?**

Question 2:

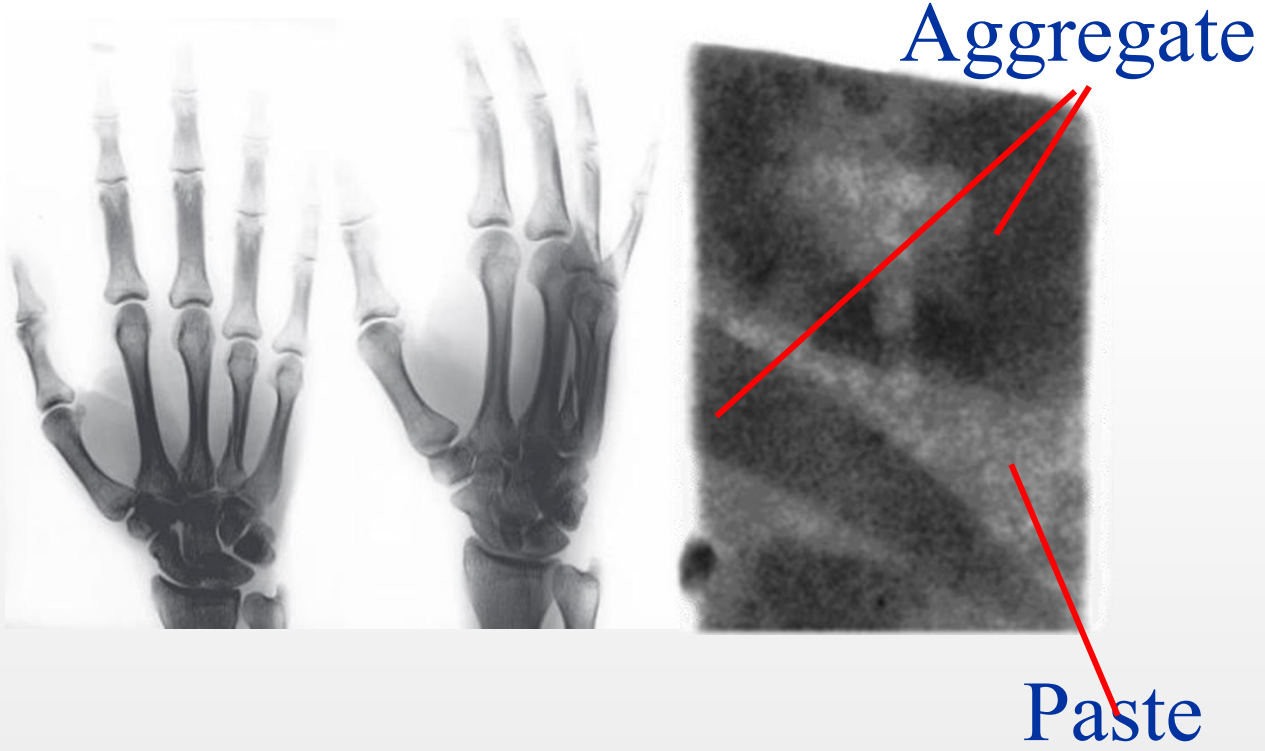
- **How to Evaluate the Effectiveness of Silane?** ***(no standard test method)***

TXM Method



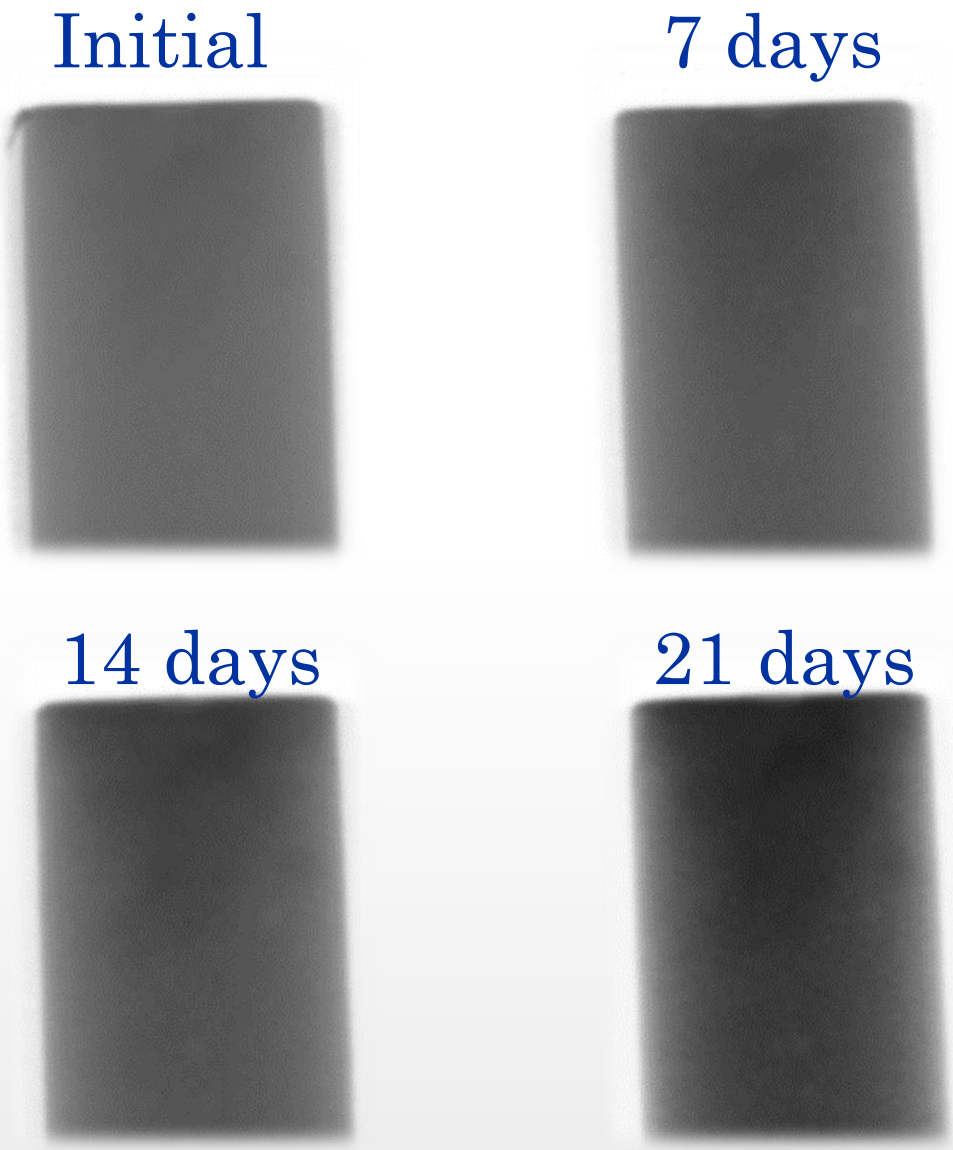
1

Put the sample between X-ray Source and detector to get a radiograph image;



TXM Method

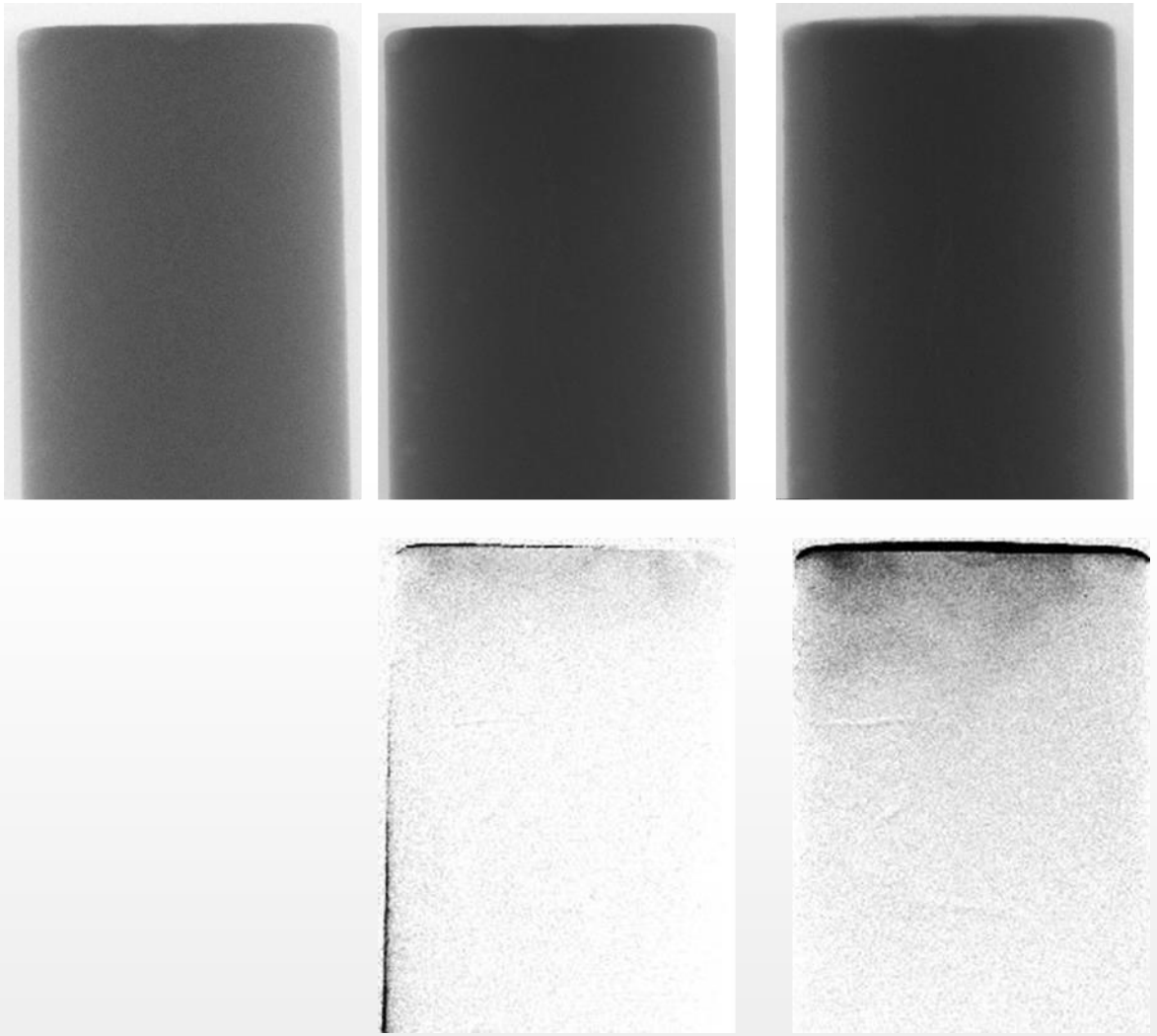
1. Put the sample between X-ray Source and detector to get a radiograph image;
2. Reference image; consequent images after applying KI;
3. Compare the gray value change over time;



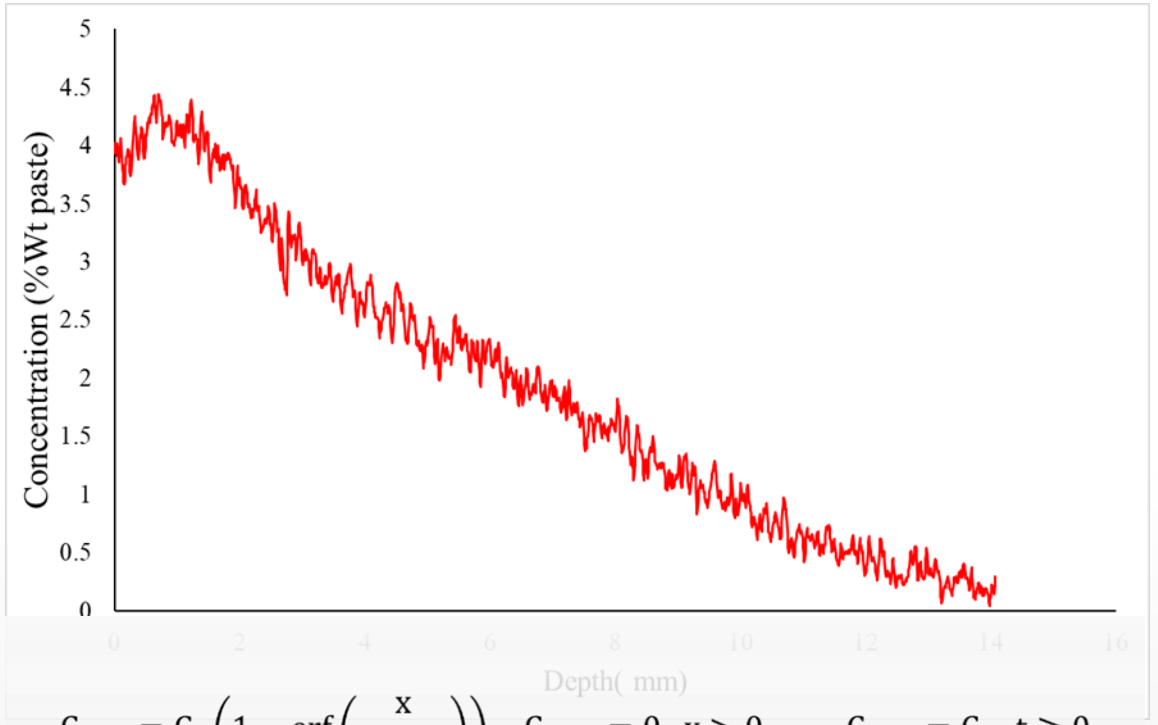
Initial

1 days

28 days



Ponding period



$$C_{(x,t)} = C_s\left(1 - \mathrm{erf}\left(\frac{x}{2\sqrt{D_c t}}\right)\right) \quad C_{(x,0)} = 0 \quad x > 0, \qquad C_{(0,t)} = C_s \quad t \geq 0$$

x :distance from sample surface

t: time

C_s: surface ion concentration

$C_{(x,t)}$: ion concentration at the depth of x from the surface after time t

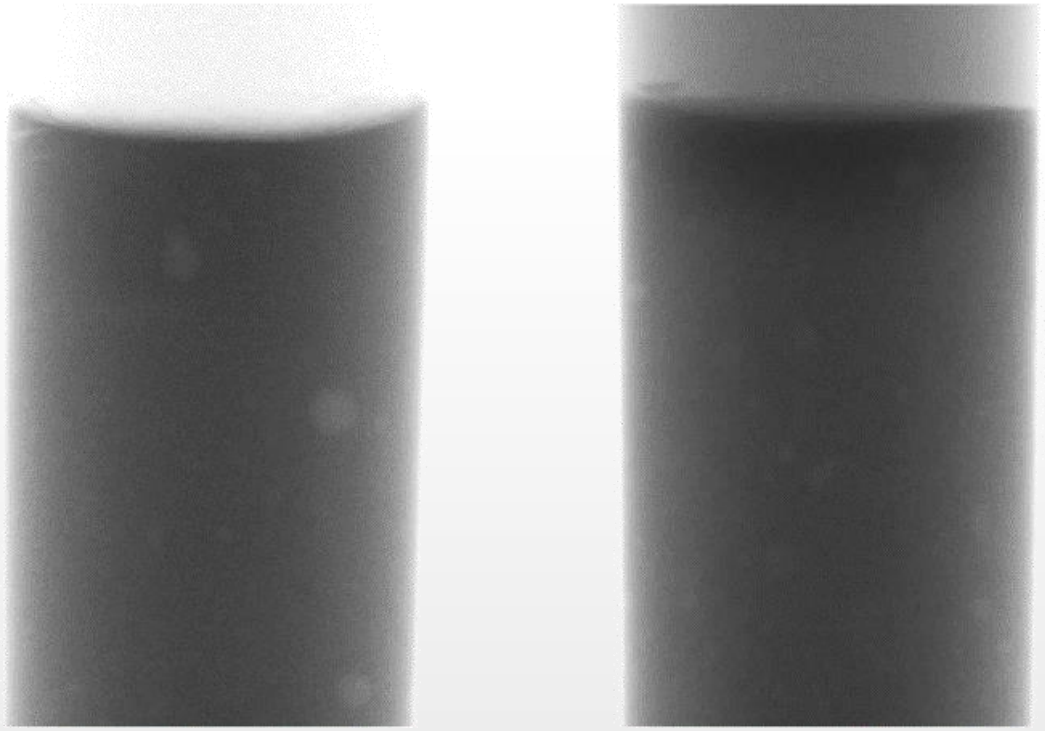
D_c: the apparent diffusion coefficient

Why did we use KI?

Materials with low electron density(e.g. Beryllium, Water, NaCl) cannot be detected in this method

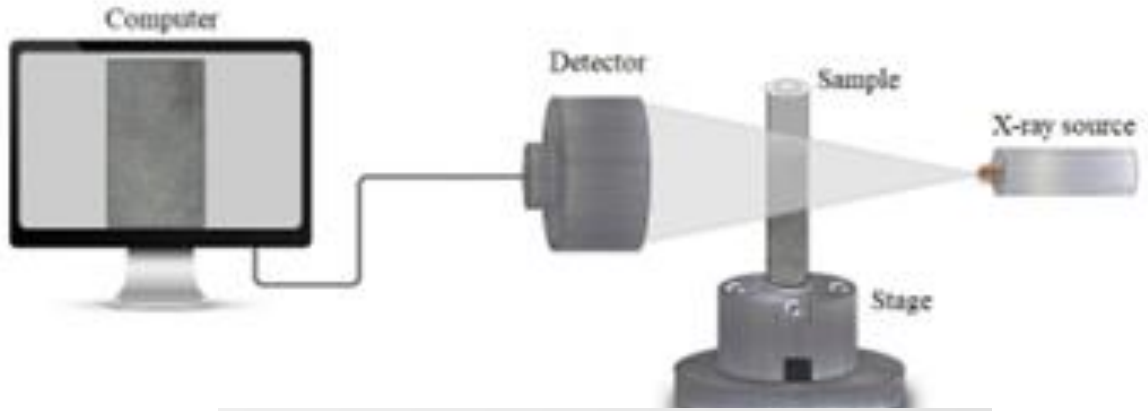
Water on top

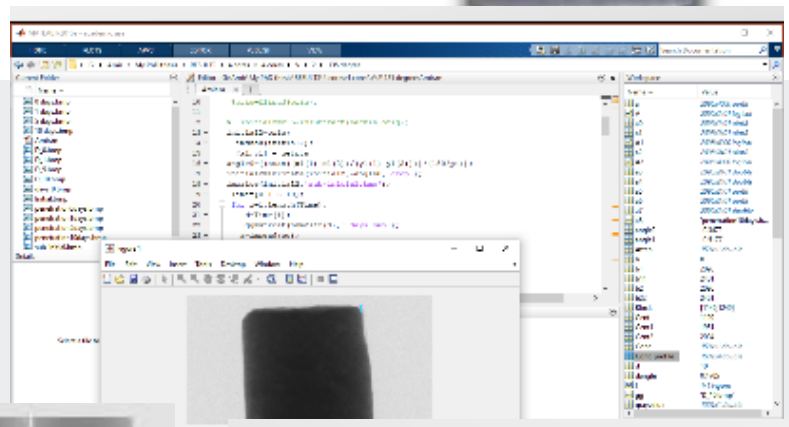
KI solution on top (0.6 Mol/L)

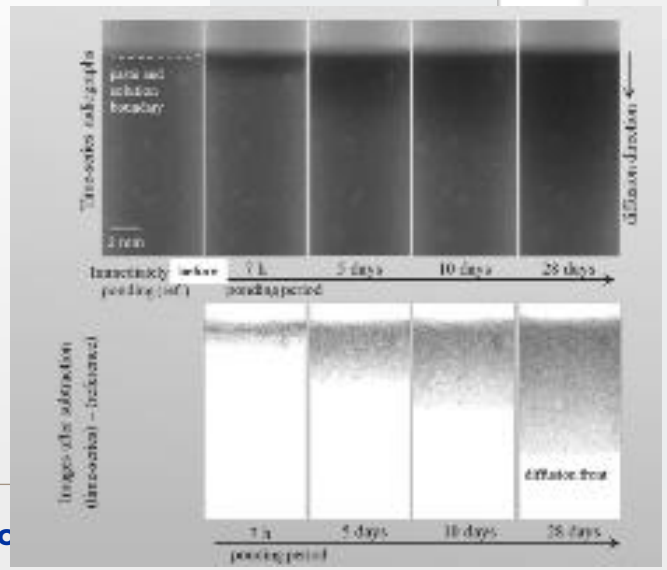


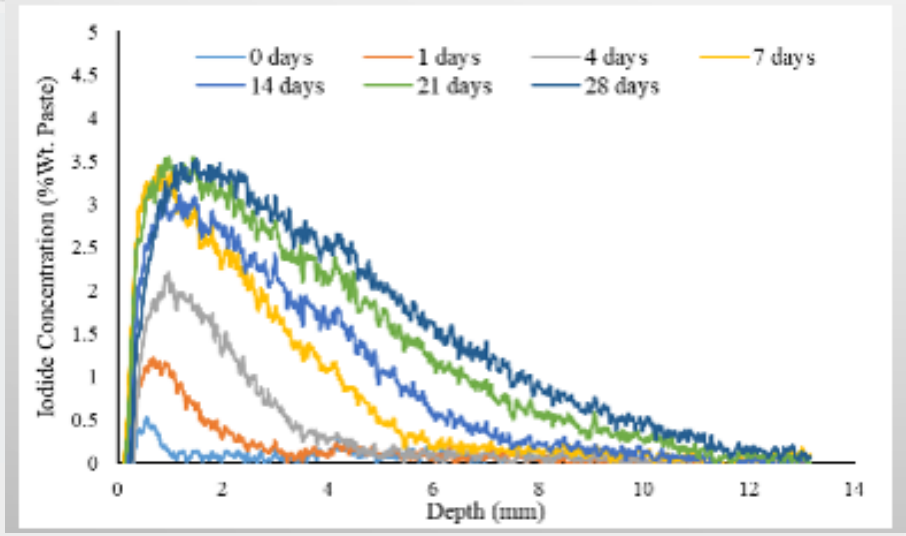
TXM Method
(summary)

- X-ray images before/after applying KI
- Monitoring the penetration of external ions
- Obtaining ion concentration profiles
- Measuring diffusion coefficient



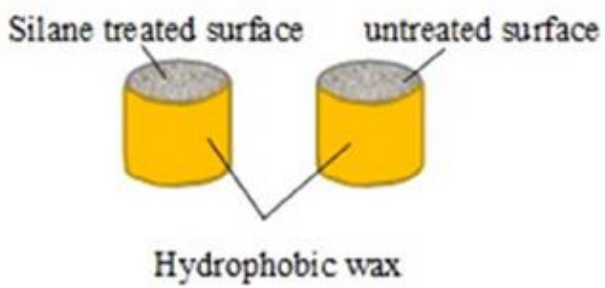


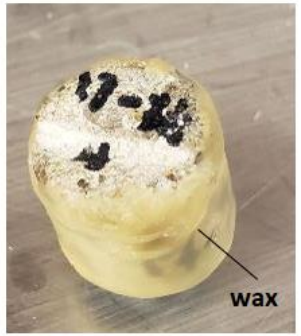




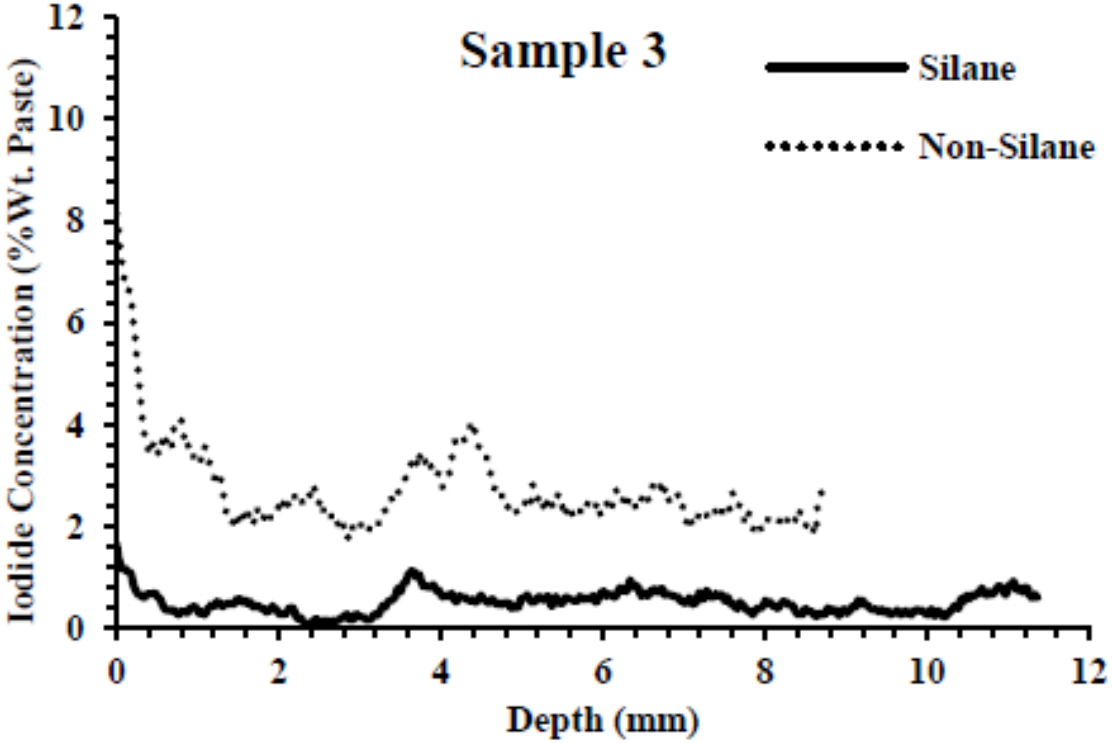
External ion penetration

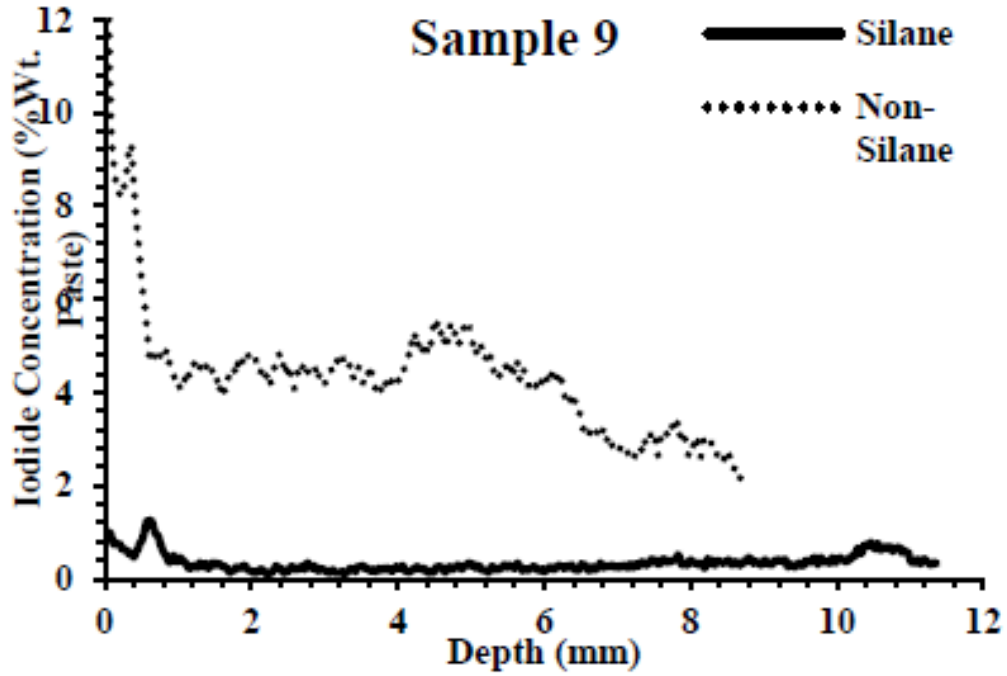
- 4 miniature cores;
- Sealing the sides of the samples;
- Obtaining reference/consequent radiographs;
- Compared the ion concentration profile, penetration depth, and ion diffusion coefficient between silane-treated and untreated samples.



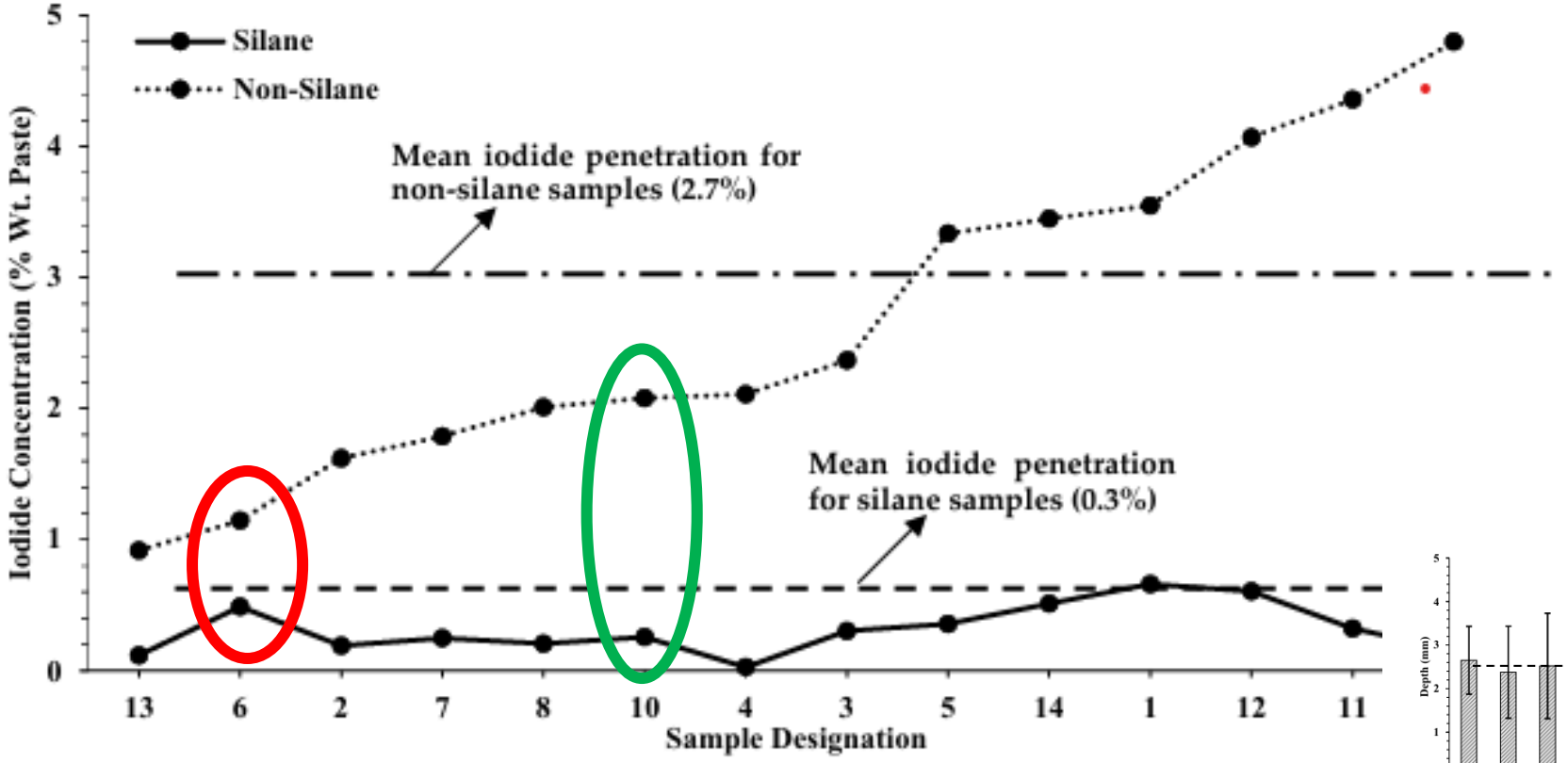


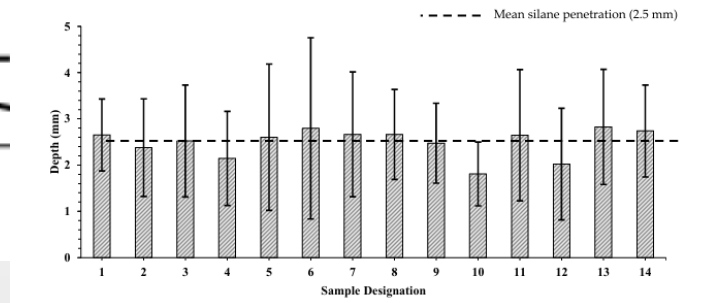
Typical Concentration Profiles for Samples with & without Silane



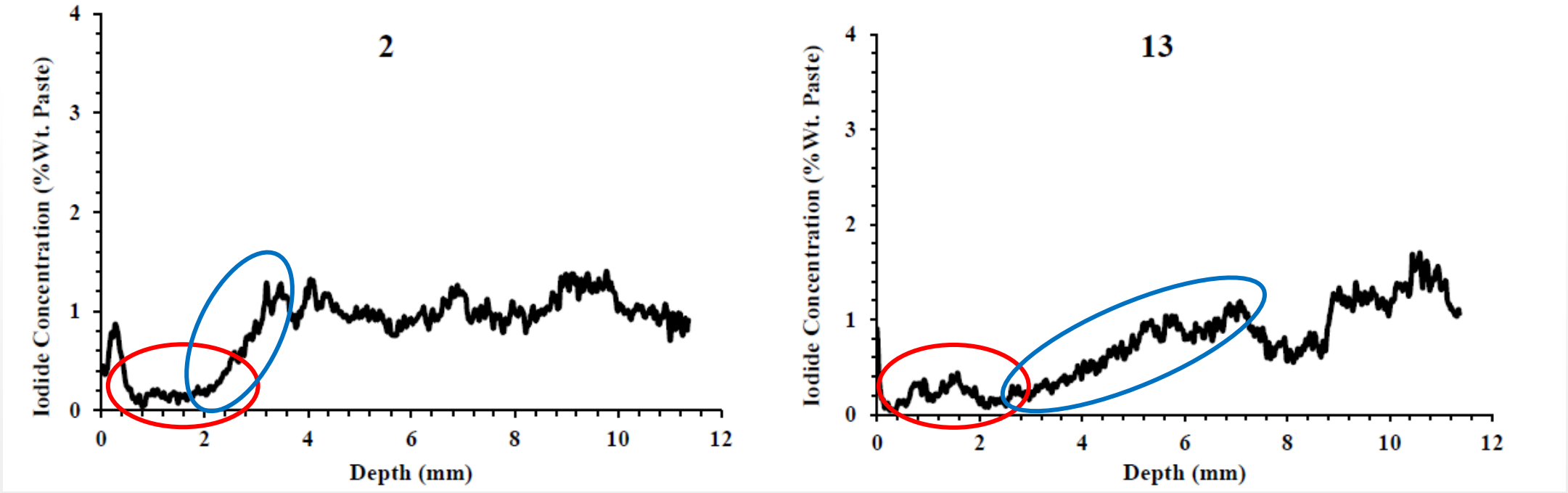


Comparison of Silane-Treated vs. Untreated Samples at 2 mm Depth





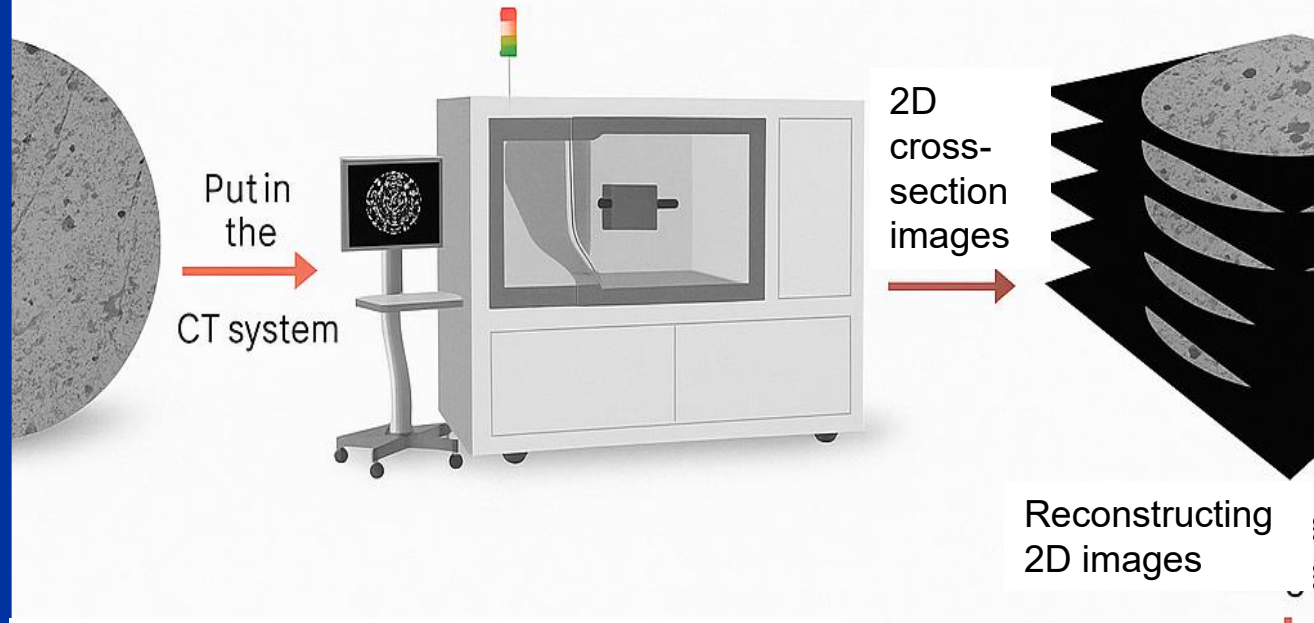
Concentration profiles

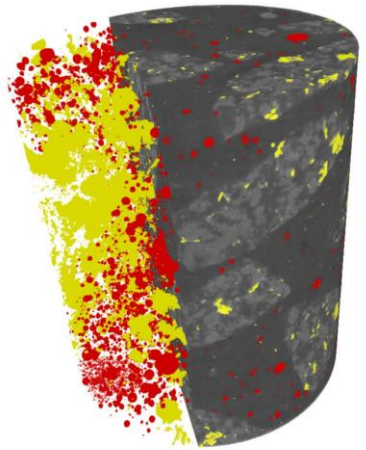


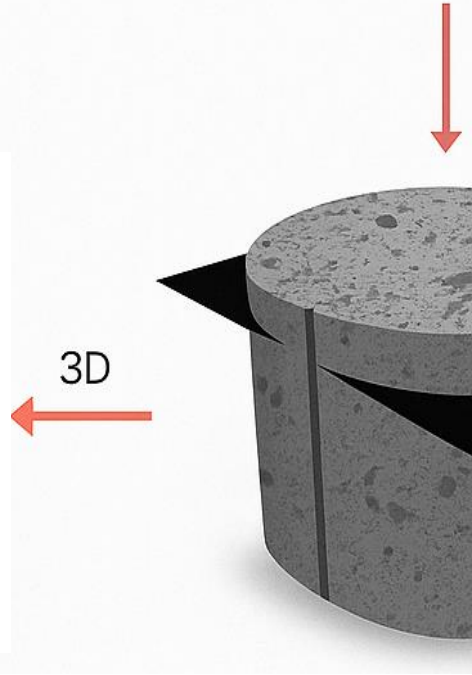
X-Ray Computed Tomography (XCT)

- **Resolution (µm/pixel): 15.29**
- **Number of projections: 1014**

- Images are captured at many different viewing angles;
- These images are used to make a 3D image called a tomograph;
- Like the gray values in the TXM radiographs, the voxel values in the tomograph represent materials with different chemical consistency and density.



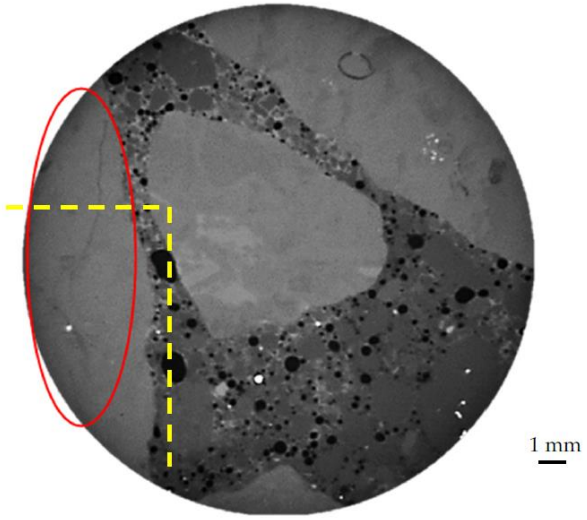


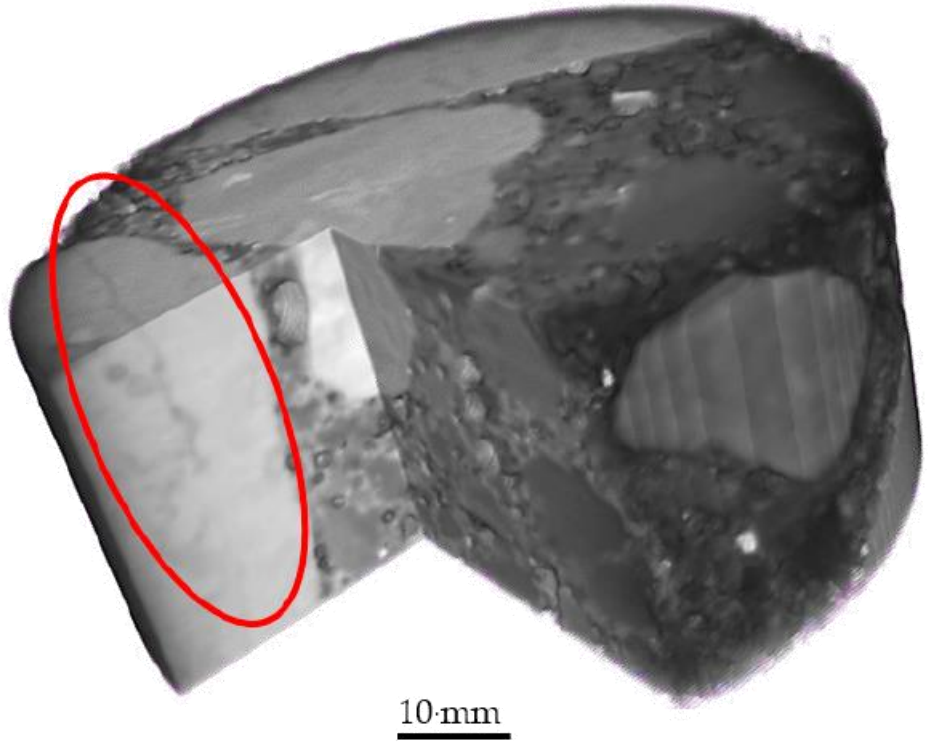


X-Ray Computed Tomography (XCT)

- **Resolution (µm/pixel): 15.29**
- **Number of projections: 1014**

- Images are captured at many different viewing angles;
- These images are used to make a 3D image called a tomograph;
- Like the gray values in the TXM radiographs, the voxel values in the tomograph represent materials with different chemical consistency and density.

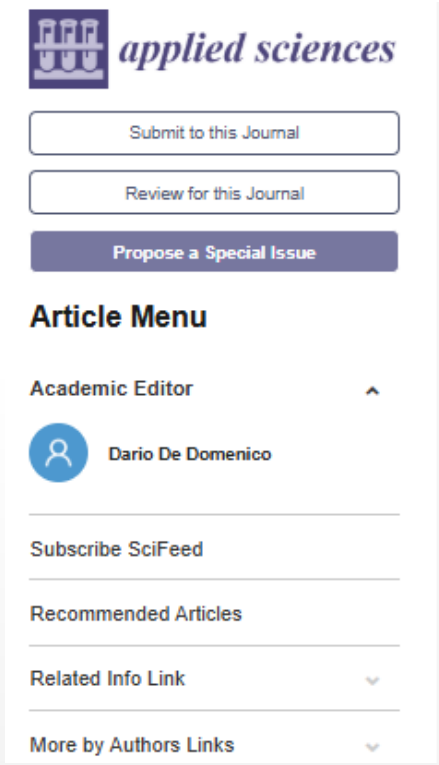


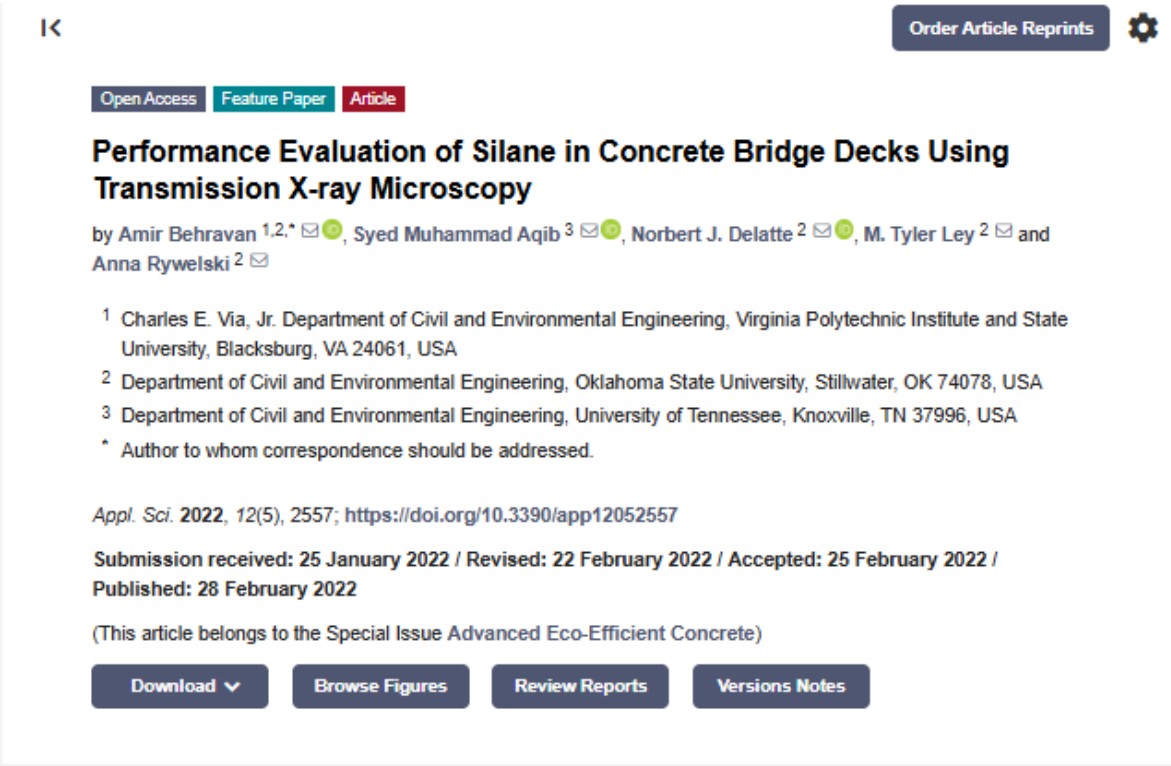


Conclusion

- Silane penetration was below specification limits.
- Despite this, treated samples showed ~9x less chemical ingress than untreated ones.
- Surface cracks allowed chemicals to bypass the coating, indicating crack vulnerability.

Publication





Amir.behravan@vdot.virginia.gov

Thank you for your attention