

Use of Silanes to extend the life of structural concrete



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Overview:

- Introduction to concrete coatings
- History of silanes in Oklahoma
- Performance of silanes
- How long do silanes last?

One way to extend the service life of concrete is to keep water and salts out.

We can do this with:

- 1. Low permeable concrete**
- 2. Coatings**

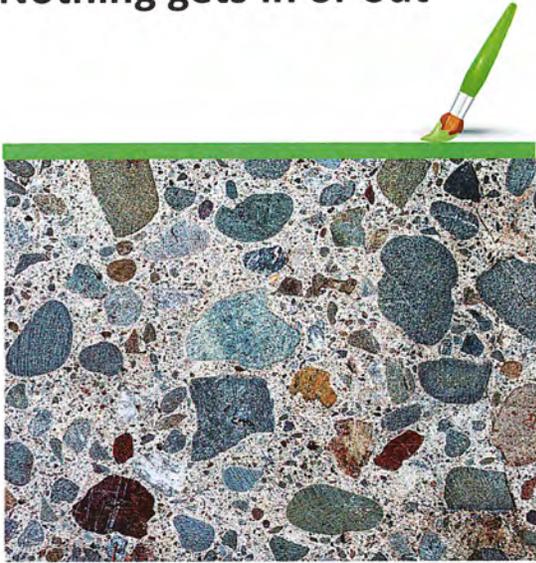


Keep Out

Types of Coatings/Sealers:

- Impermeable**
- Reactive**
- Vapor Permeable**

Impermeable Sealer – Nothing gets in or out



Impermeable Sealer Types:

- Epoxy
- Asphalt based
- Rubber cements
- +more



Why are they useful?

They are useful when your concrete is exposed to constant moisture. Impermeable Sealers keep moisture out.



Impermeable Sealer Challenges:

- Damaged regions or pin holes allow moisture through
- Seals moisture in concrete that can cause other durability issues
- They often debond and fail
- Can't see cracks

**Reactive Sealer – Penetrate into the concrete
and cause pores to get smaller**



Reactive Sealer Types:

- **Hardners**
 - **Li, Ca, K, Silicates**
 - **Amorphous silica**
 - **Colloidal silica**
- +more**

Why are they useful?

They can decrease the permeability of your concrete at the surface.

Reactive Sealer Challenges:

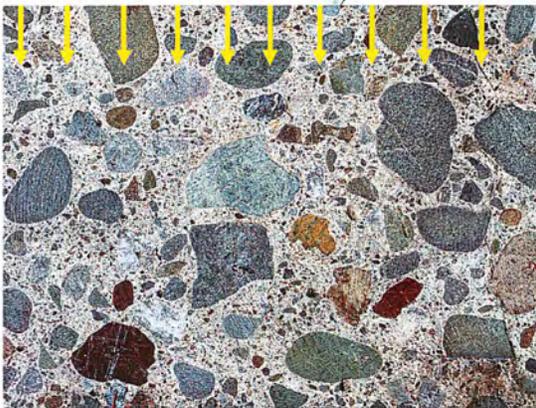
- **Only works at the surface**
- **Unclear the best time to apply**
- **Performance depends on the quality of the concrete**
- **Challenging to quantify benefits**
- **Higher costs**

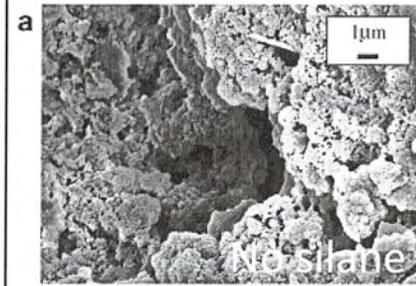
Vapor Permeable Sealer –
NO liquid in but **vapor** in/out



Vapor Permeable Sealer –
NO liquid in but **vapor** in/out

Penetrates and
reacts in pores



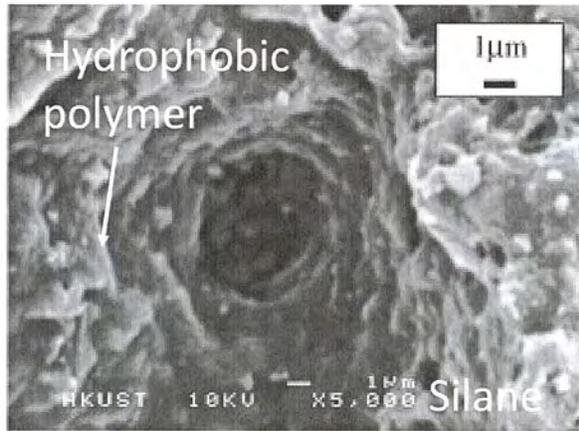


No Silane



Silane Present

Woo et al., 2008



Silane with Hydrophobic Polymer

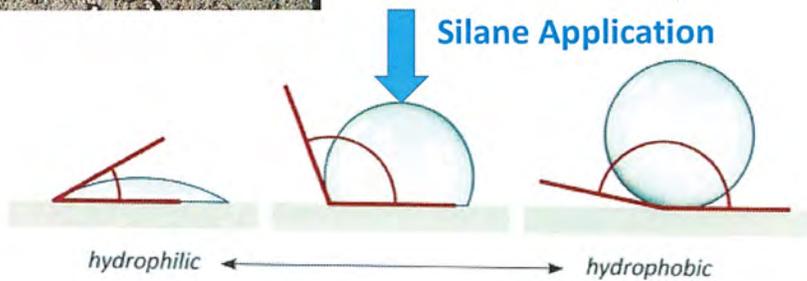
Why are Hydrophobic properties important?
Repels water! 😊

Woo et al., 2008

Silanes make the surface hydrophobic!!!



Why are some droplets round?



Vapor Permeable Sealer Types:

- Silane
- Siloxane
- Latex
- +more



Why are they useful?

A low cost method to decrease the permeability of your concrete at the surface.

Vapor Permeable Sealer Challenges:

- **Concrete moisture is important at application. You want your concrete dry.**
- **Surface preparation is critical**
- **Harder to penetrate low permeability concrete**

Vapor Permeable Sealer –

- Since vapor can get in and out then the concrete will dry.
- This is great for ASR, Freeze thaw, corrosion, carbonation

History of silane usage at ODOT

- The first silane was used in 1979
- All ODOT bridges are treated with silane
- Cost of silane is \$4.00/yd²
- We feel silane is an inexpensive way to extend the service life.

Bid Tab: Silane / Siloxane (Water Repellent - Performance Tested)

SECTION	0002	BRIDGE 'B'								
0004	515(B)	6014	763.000	SY	4.00000	3052.00	4.00000	3052.00	4.10000	3128.30
WATER REPELLENT (PERFORMANCE TESTED)										

Pay Item:

(A) WATER REPELLENT (VISUALLY INSPECTED)

Square Yard [Square Meter]

→ (B) WATER REPELLENT (PERFORMANCE TESTED)

Square Yard [Square Meter]

ODOT Silane Usage

- Silanes are not applied as part of the initial construction contract for a bridge.
- After one year a separate maintenance contract is let.
- The contractor will seal individual cracks on the surface with an epoxy or methacrylate and then coat the bridge with a silane.

ODOT Silane Usage

- ODOT specifications require that the silane penetrate $> 0.15''$
- This is checked by taking cores, splitting them open, and dyeing the surface to measure the depth of penetration



ODOT Silane Usage

- A penetration test is done where field cores are dried in an oven and then all sides are coated with wax except for the finished surface. They are then ponded with water to measure the water uptake through the silane.



Do silanes really work???

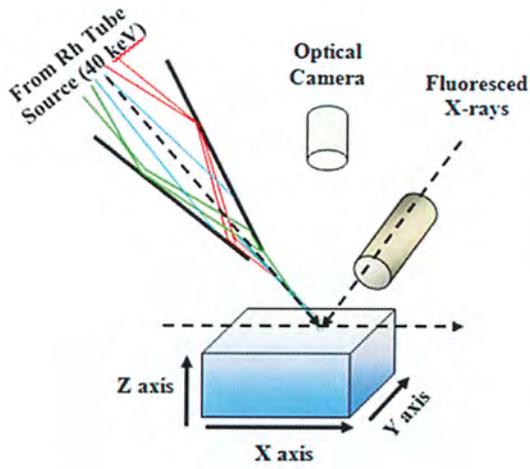
Make a 0.45 w/cm concrete mixture

Cure for 28d and coat the cylinders with silane, silane + epoxy, or nothing

Pond the cylinders with 4% NaCl

Cut the cylinders and measure the Cl concentration

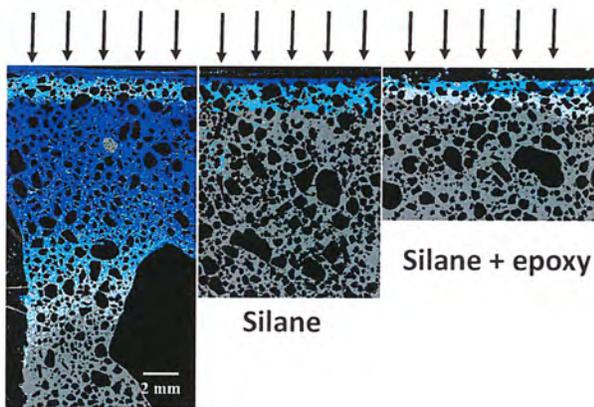
μXRF technique description



Khanzadeh Moradllo, Sudbrink and Ley, 2016

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Chlorides applied here



Black – aggregates
 Light blue – low chlorides
 Sky blue – medium chlorides
 Dark blue – high chlorides

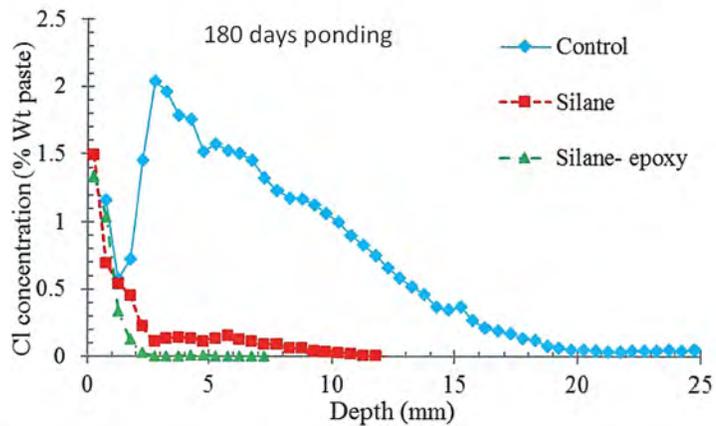
180 days of ponding with 4% NaCl 0.45 w/cm

Control

Silane

Silane + epoxy

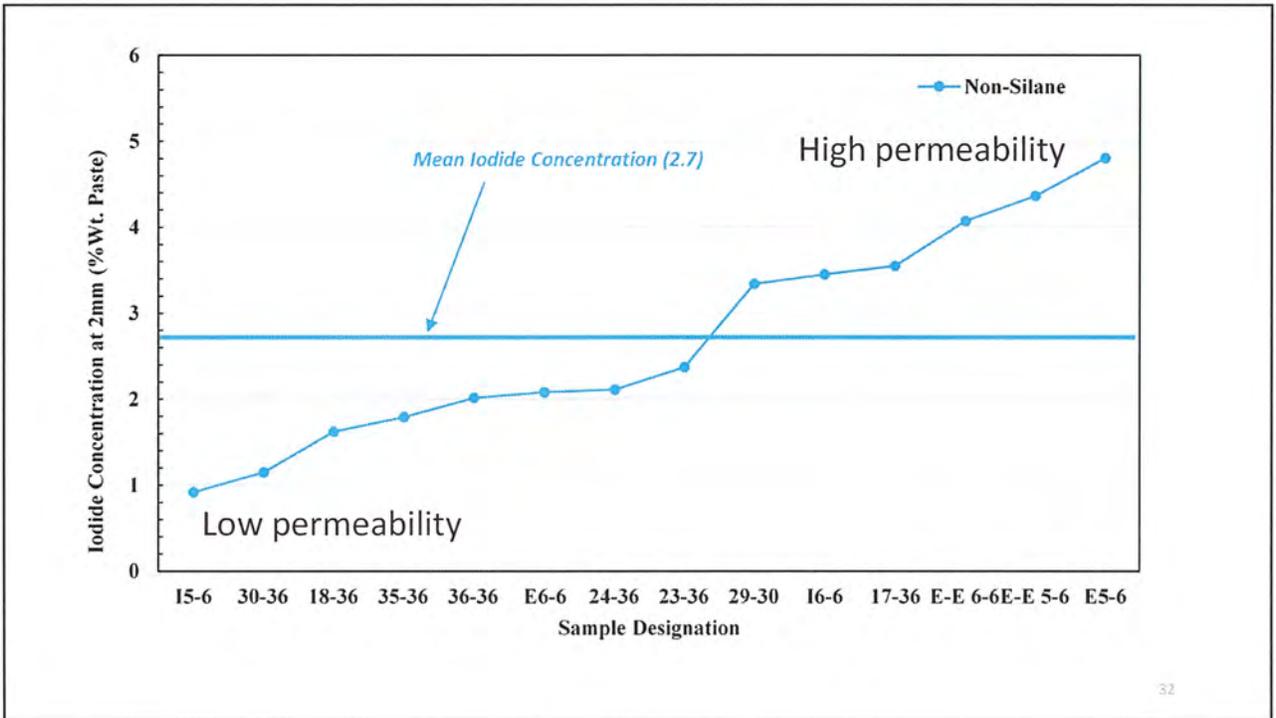
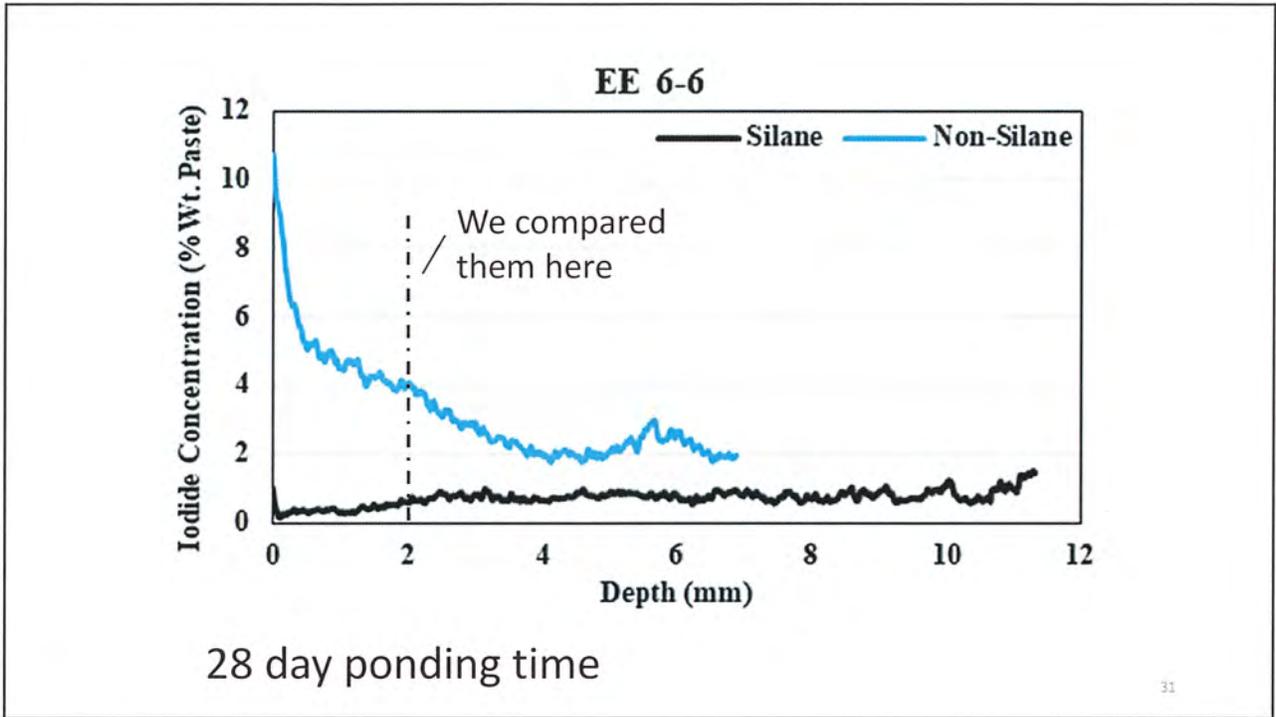
Khanzadeh, 2017

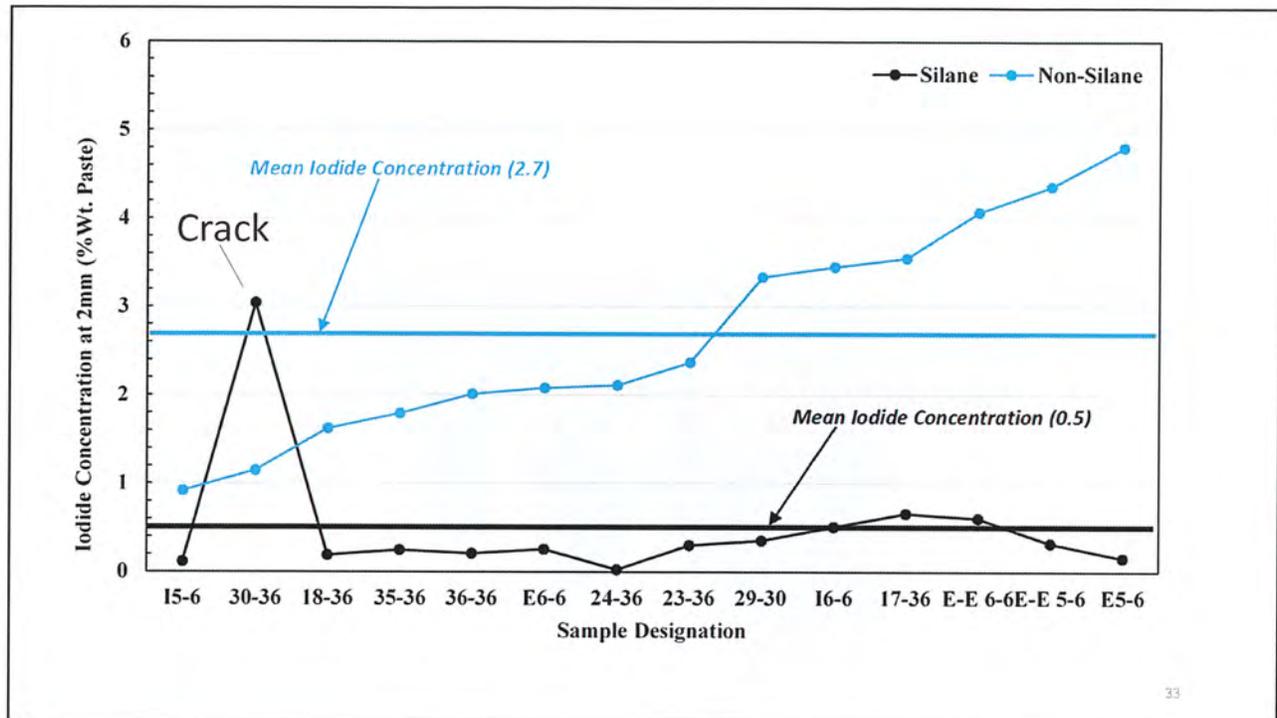


This is the same data as the images but shown graphically.

How does silane perform in the field???

- Oklahoma DOT provided 14 cores from recently completed bridge decks.
- They wanted to compare the permeability of the base concrete and the reduction in permeability from the silane.





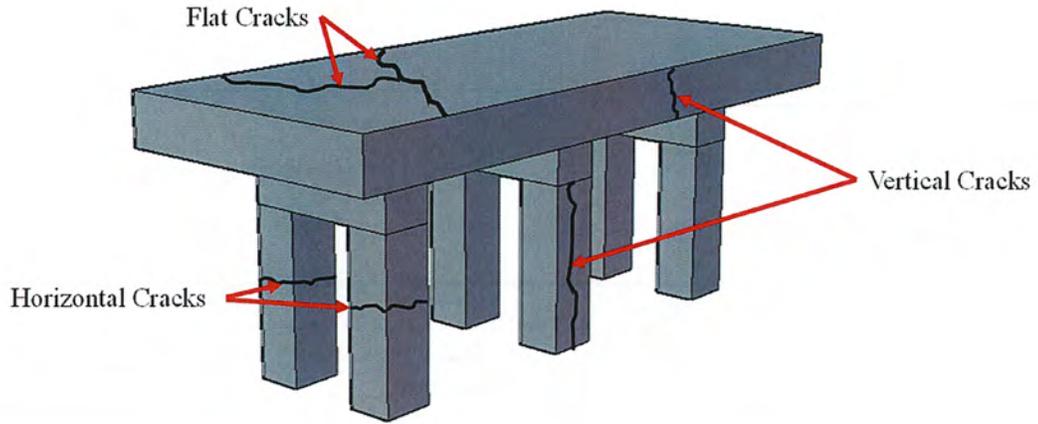
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Summary

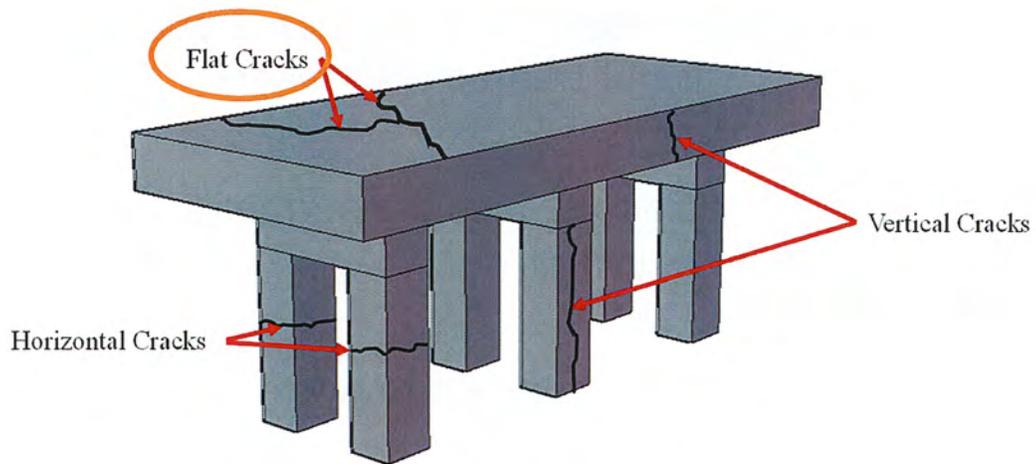
- There was a large difference in the permeability of the concrete that was not treated with silane.
- The silane was able to reduce the permeability of all the concrete investigated.
- NOTE! – Silane will not penetrate w/cm < 0.35.

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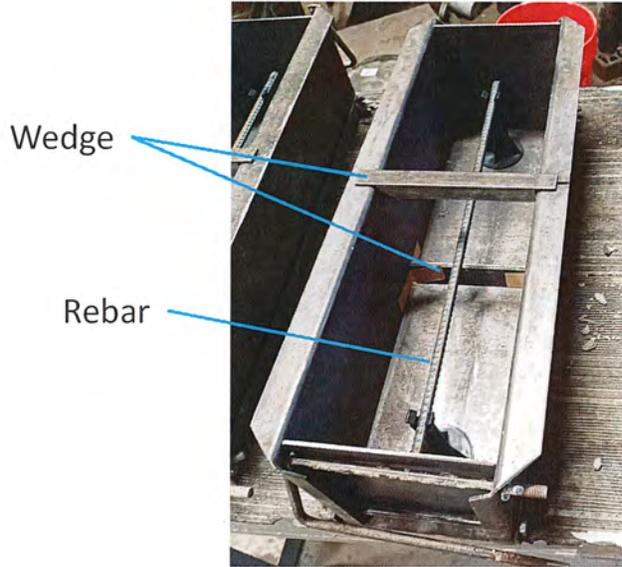
How does silane perform in cracked concrete?



How does silane perform in cracked concrete?

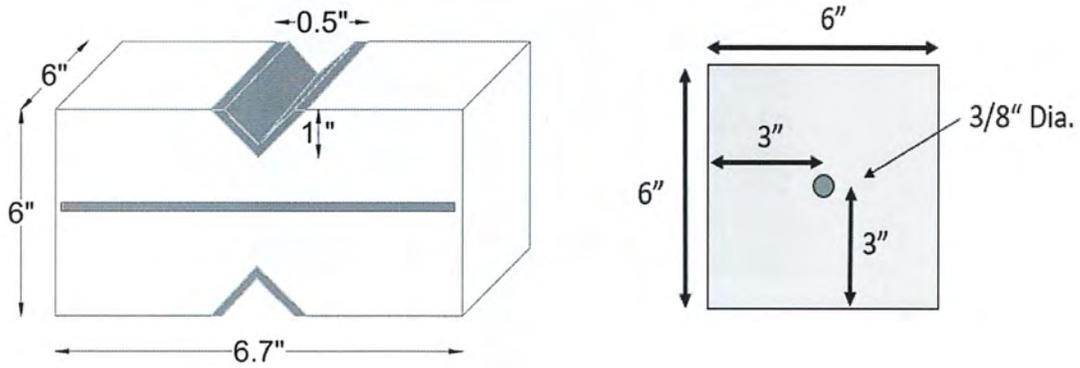


How do we make the cracks of known sizes?

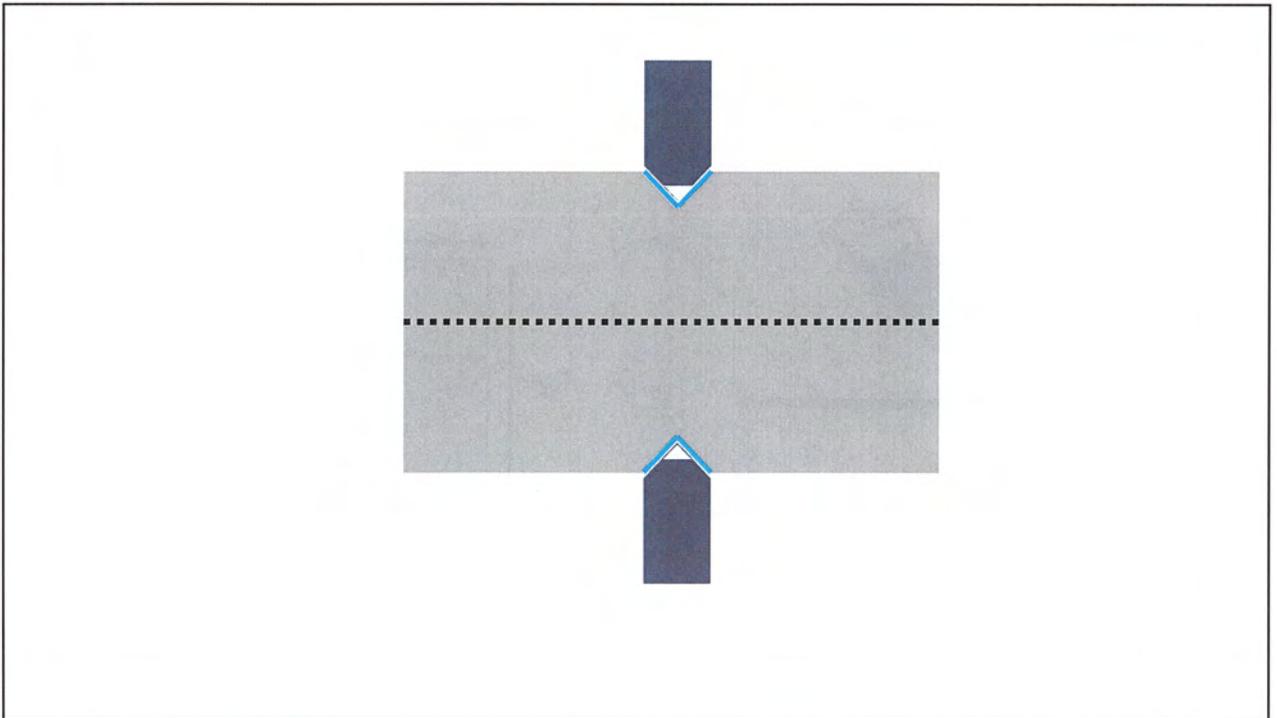
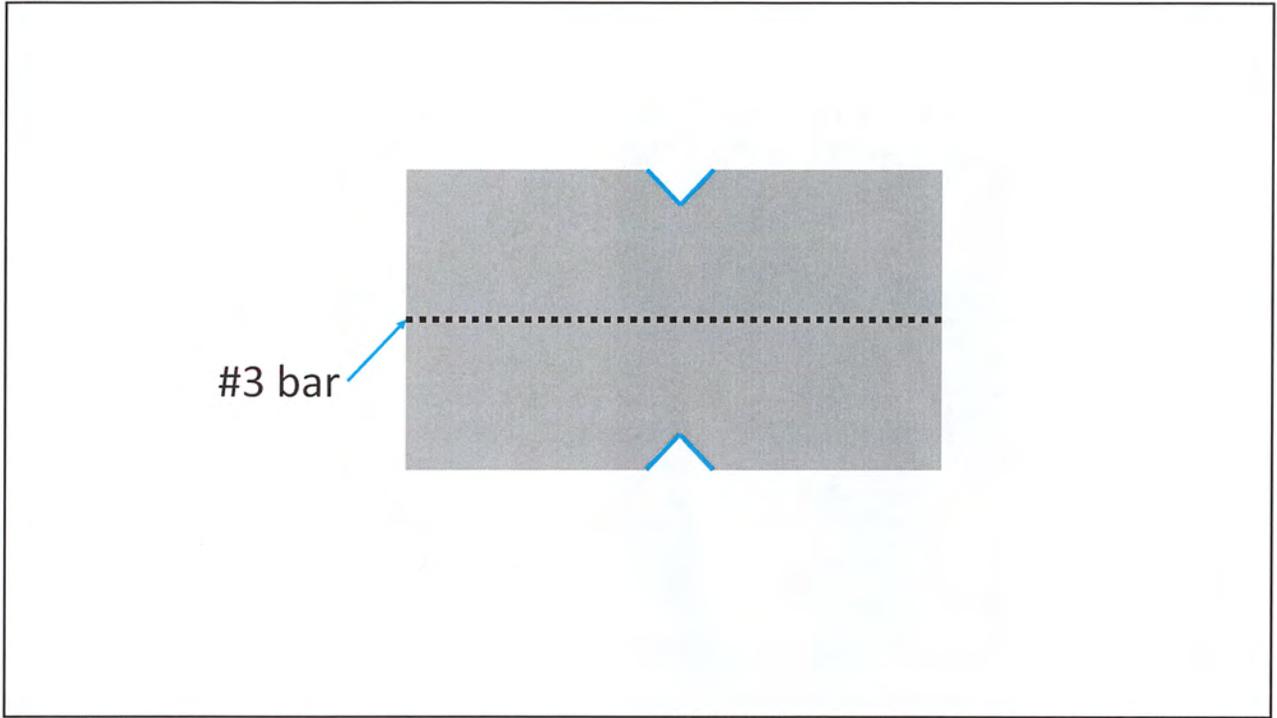


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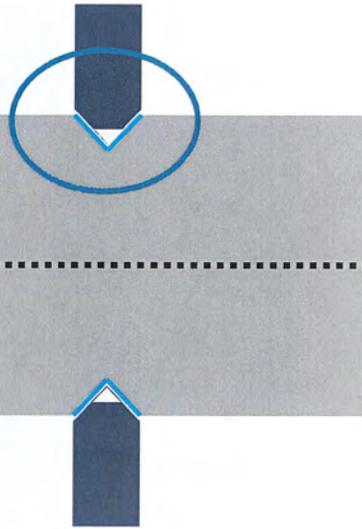
Split Beam



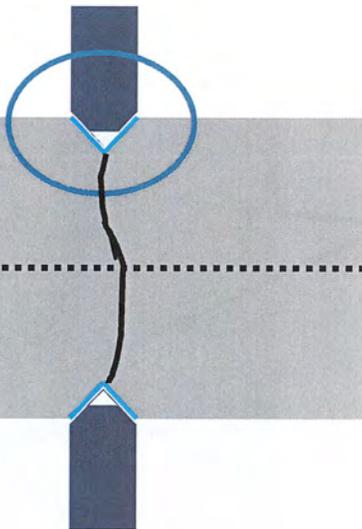
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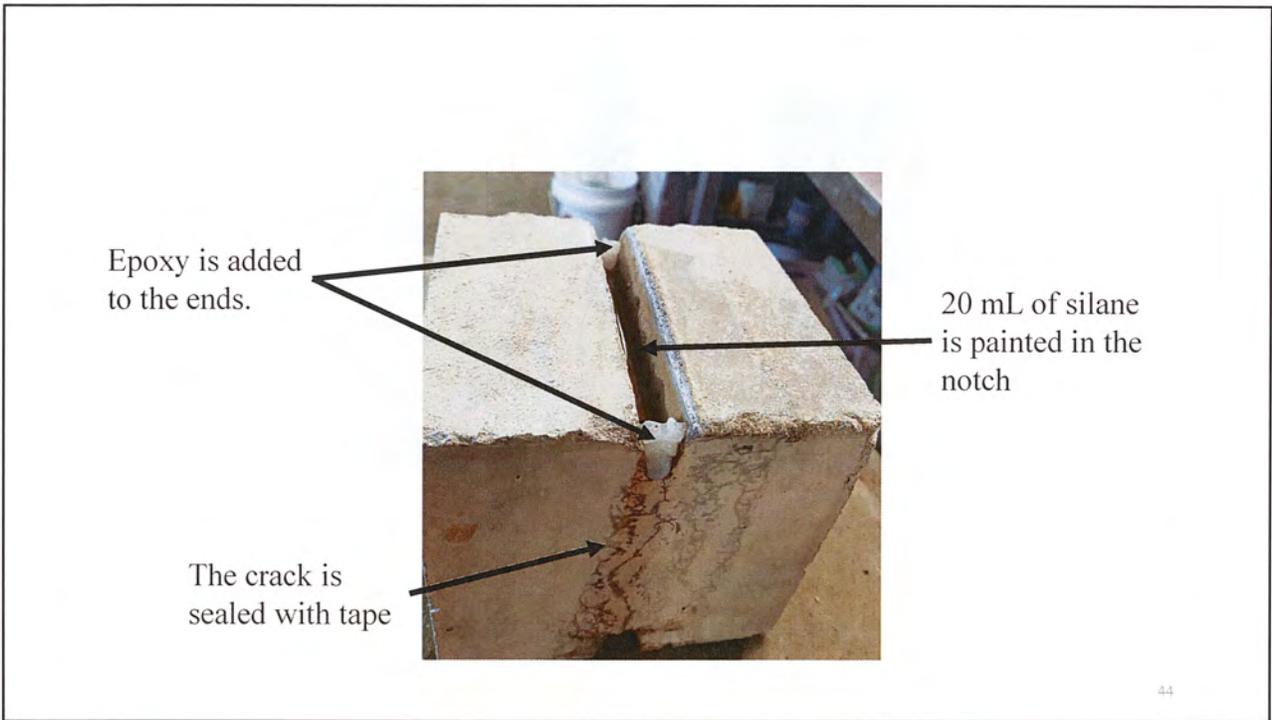
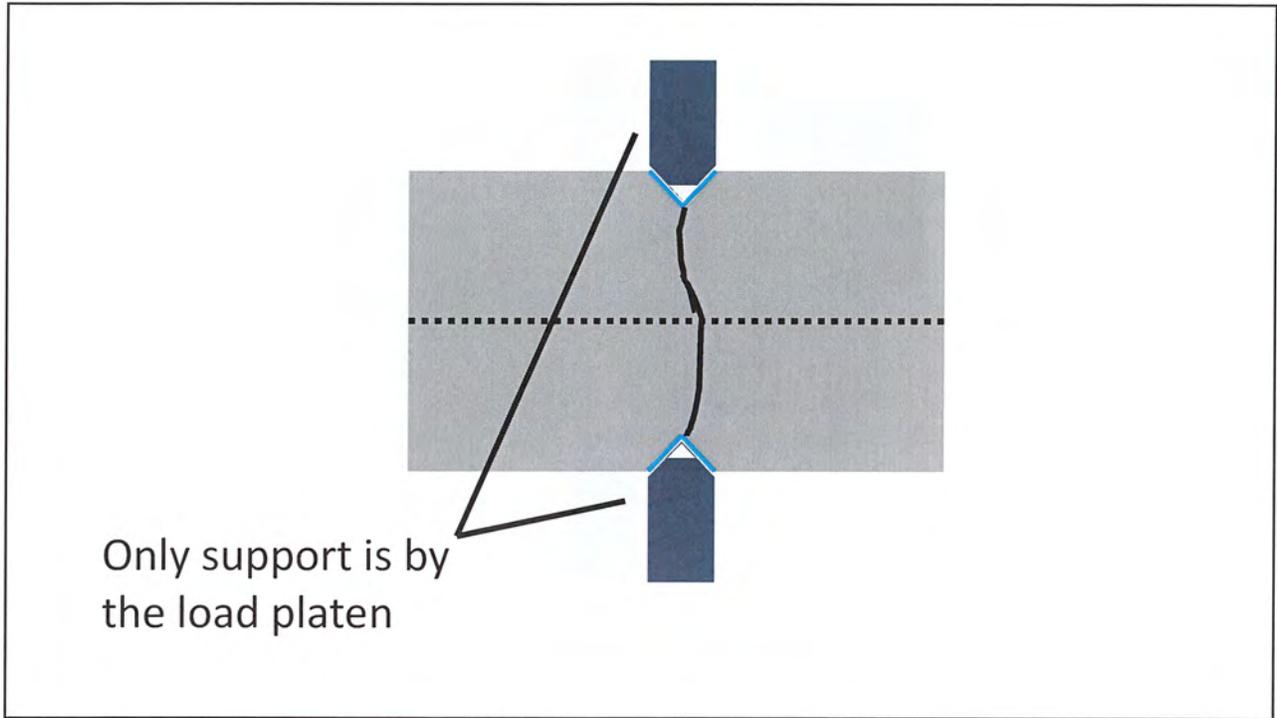


Two wedges that are not connected

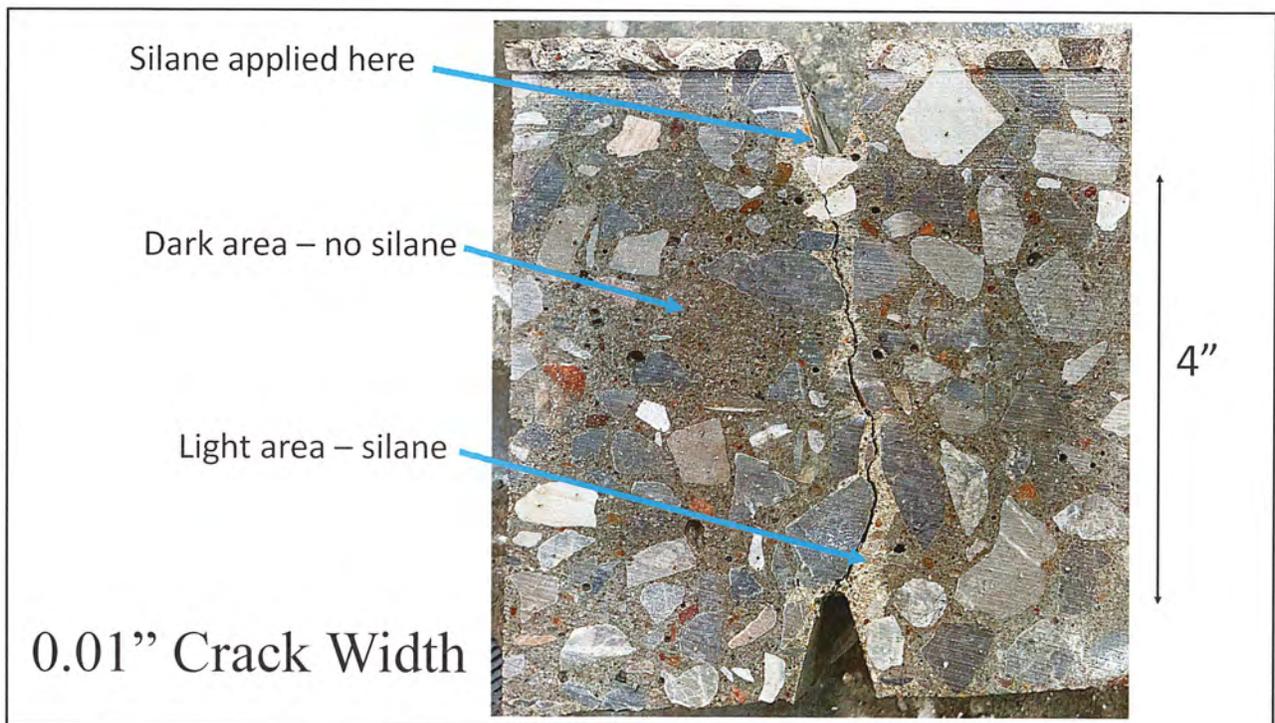
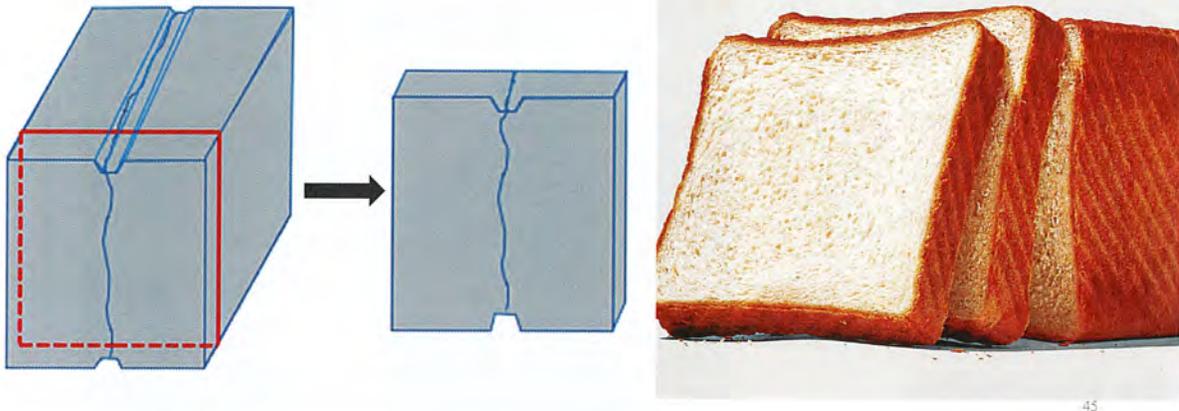


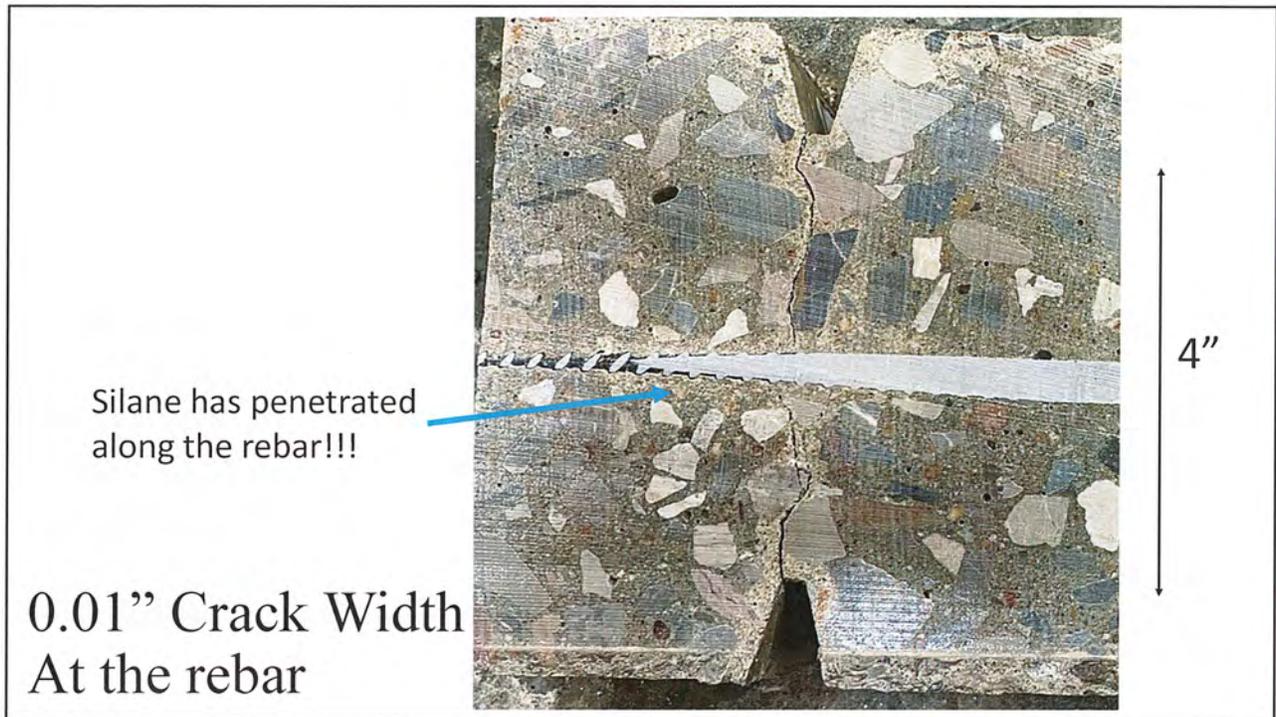
No connection





After 7 days, the samples are cut like a loaf of bread and water is added to the surface to see where the silane is present.





Discussion

Silane can penetrate and coat the 0.01" crack!

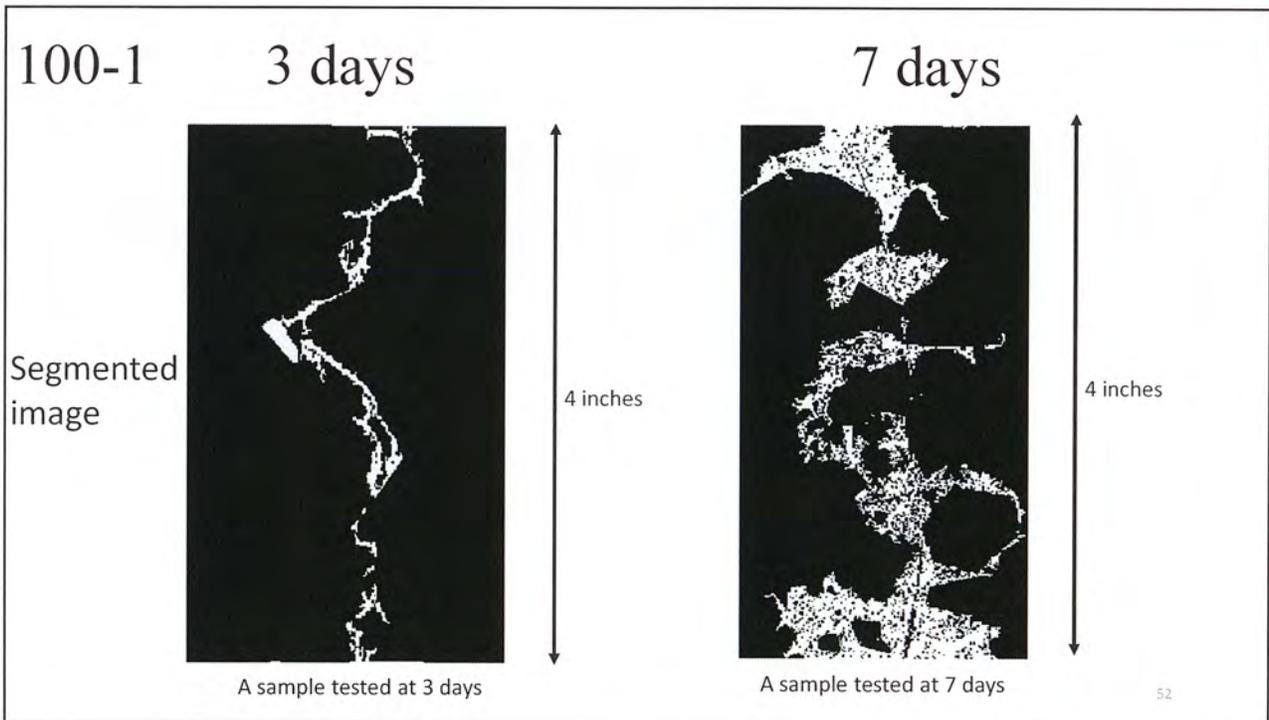
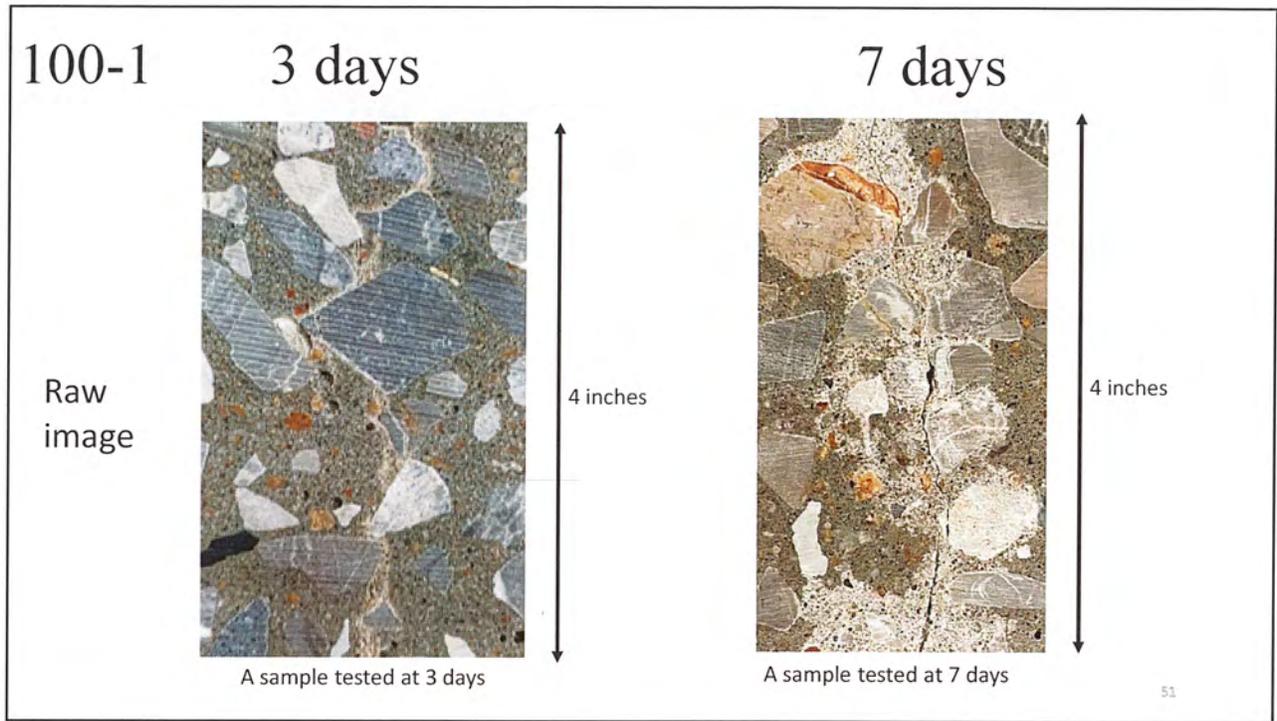
Silane can coat the rebar.

Do all silane products perform the same?

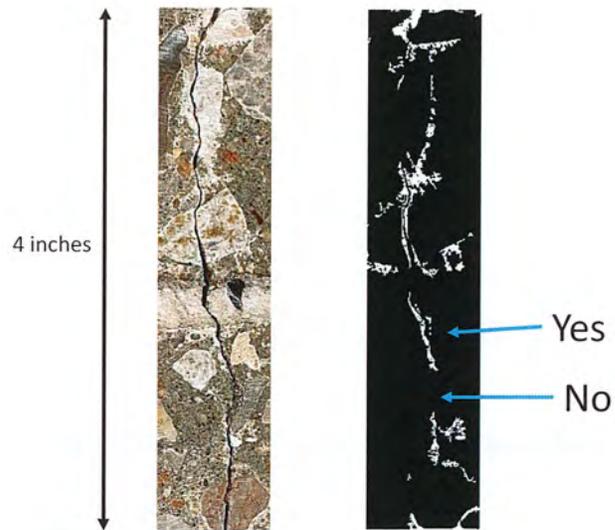
Does the penetration change with time?

Products

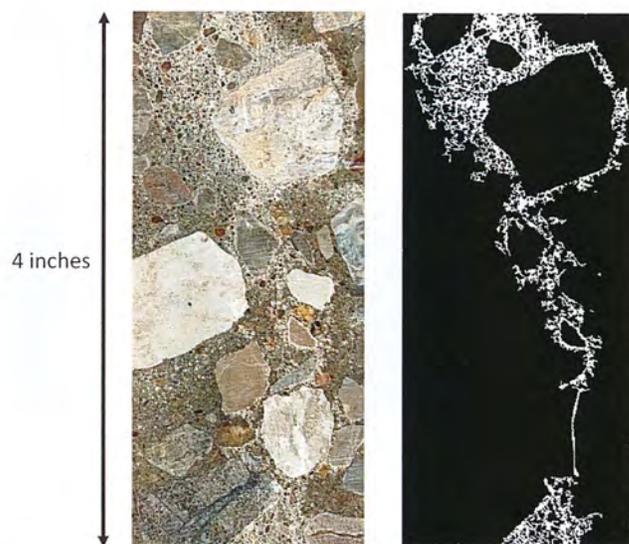
Name	100-1	100-2	40-1	100-3	40-2	100-4
Density (lb/gal)	7.36	7.68	7.68	7.68	7.68	7.34
VOC Content g/L	< 400	< 400	< 600	<350 g/l	-	<390
Silane Type	Not Given	Isobutyl trimethoxysilane	Isobutyl trimethoxysilane	Isobutyl trimethoxysilane	Isobutyl trimethoxysilane	Triethoxyiso butylsilane
Chemical Nature	Not Given	Alkoxysilane	Alkoxysilane	Alkoxysilane	Alkoxysilane	-
Solvent	Free	Methanol	Methanol	Methanol	Methanol	-
Corrosion Inhibitor	Yes	Yes	No	No	Yes	No
pH	11	Not Specified	Not Specified	Not Specified	Not Specified	Not Specified
Active Ingredients (%)	98%	90-98%	35-45%	90-100%	42%	90-100%



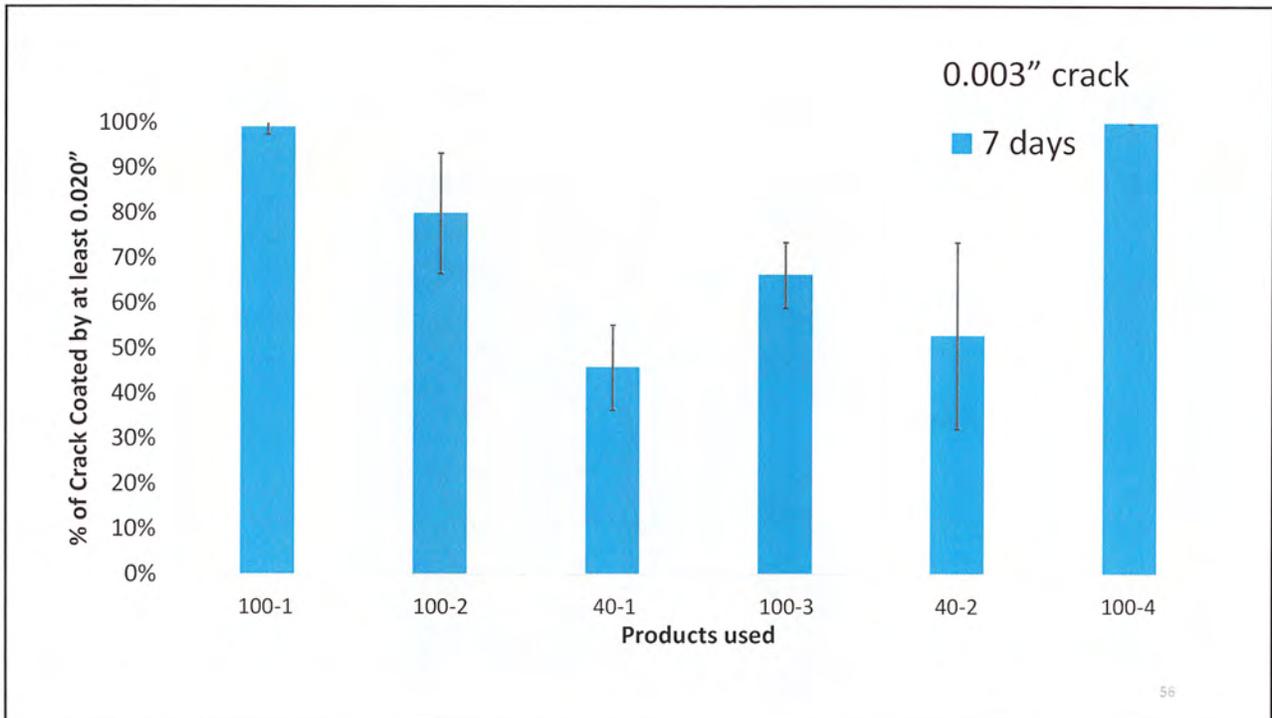
What percentage of the crack is coated?



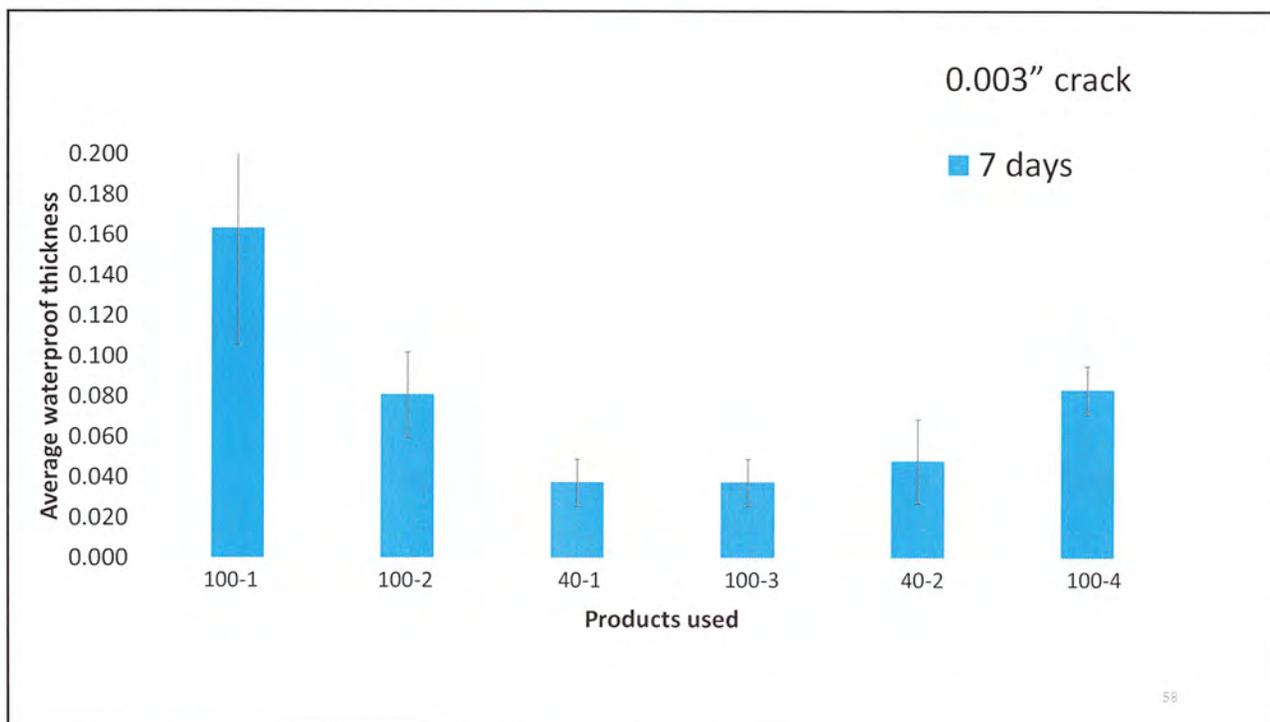
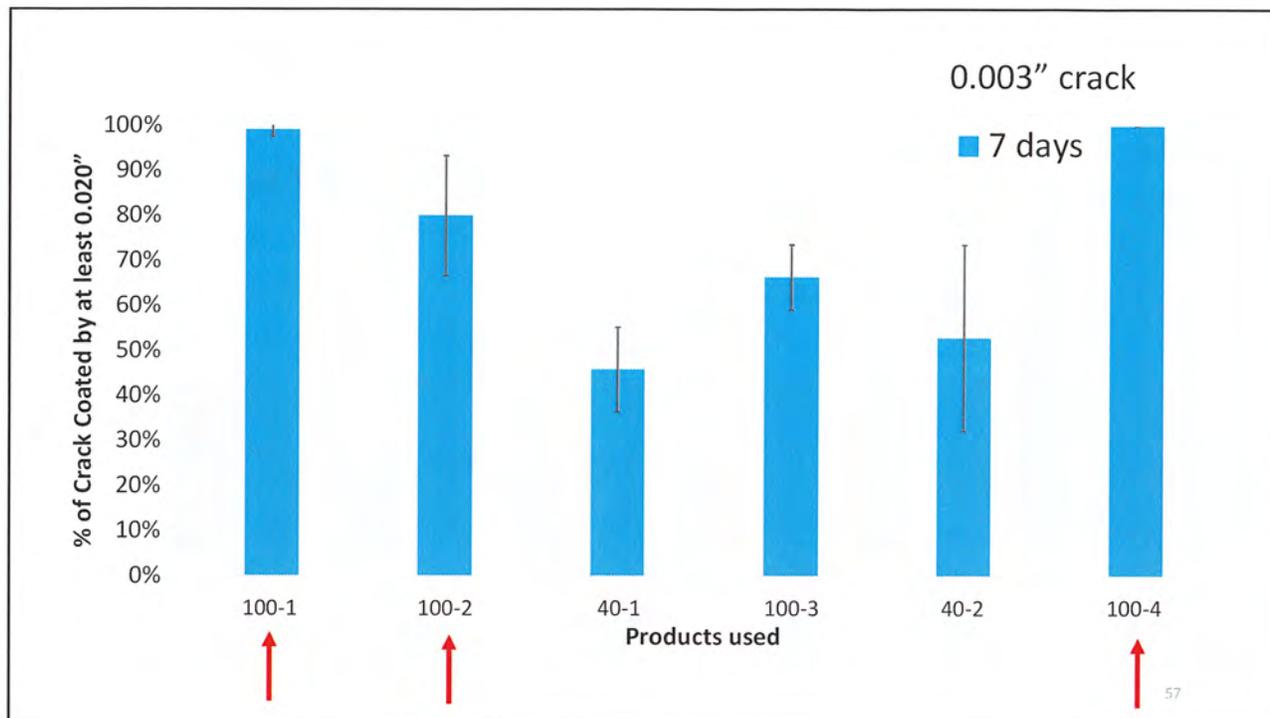
What is the average coating thickness?

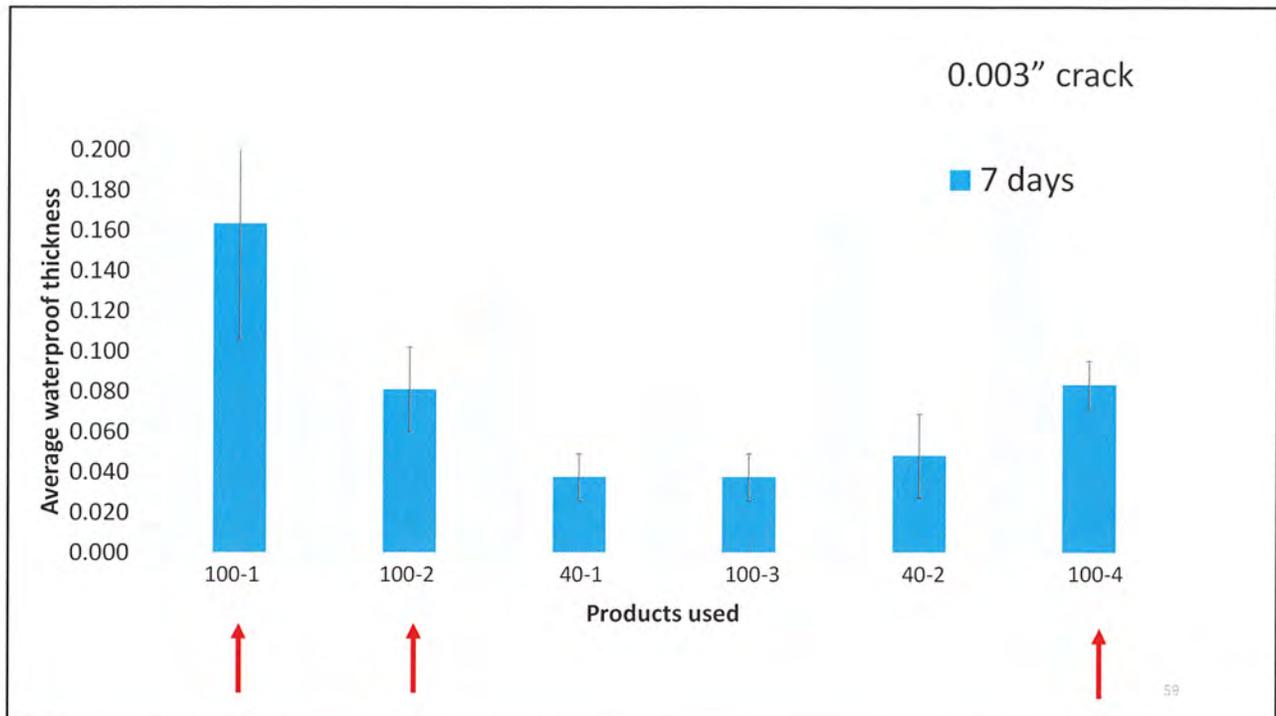


Let's compare the different products at the smallest crack size!



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Discussion

- All of the silanes penetrated the cracked concrete!
- The 90-100% active ingredients did a better job at coating the cracks and creating a thicker layer of waterproofed material.
- The VOC content did not impact the performance.

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Discussion

- **The most economical and best performing product was a 100% solids content Triethoxyisobutylsilane (Product 100-4).**
- This silane has a higher molecular weight, lower density, and the lowest VOC.

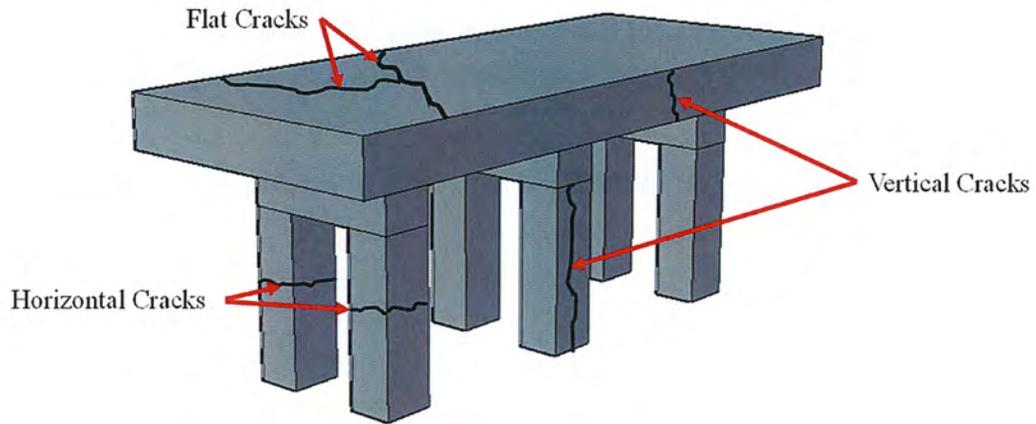
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What is next?

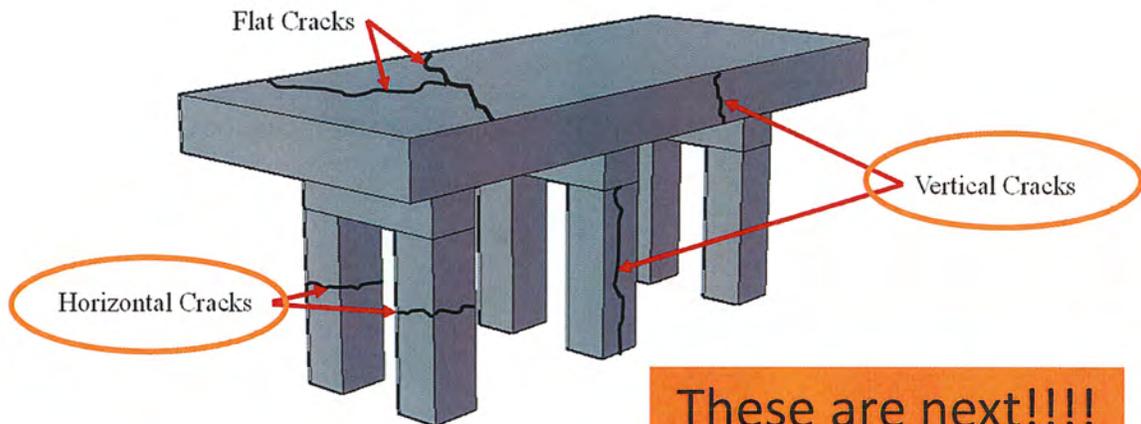
- Use 100-4 and examine the performance of the product for different crack sizes.
- Does the silane keep water from penetrating the crack (< 0.01" yes, so far!)

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How does silane perform in cracked concrete?



How does silane perform in cracked concrete?



How long does a silane coating last?

Cores were taken from 60 bridges with ages from 5 to 20y.

3 cores from the travel lane

3 cores from the shoulder

Records showed that all bridges had adequate silane penetration after installation $> 0.15''$.



A concrete counter top drill bit was used to take
1" diameter cores.



How long does it last?

Percentage with > 3 mm silane layer

Years of service <12 y | 15 y | > 17 y

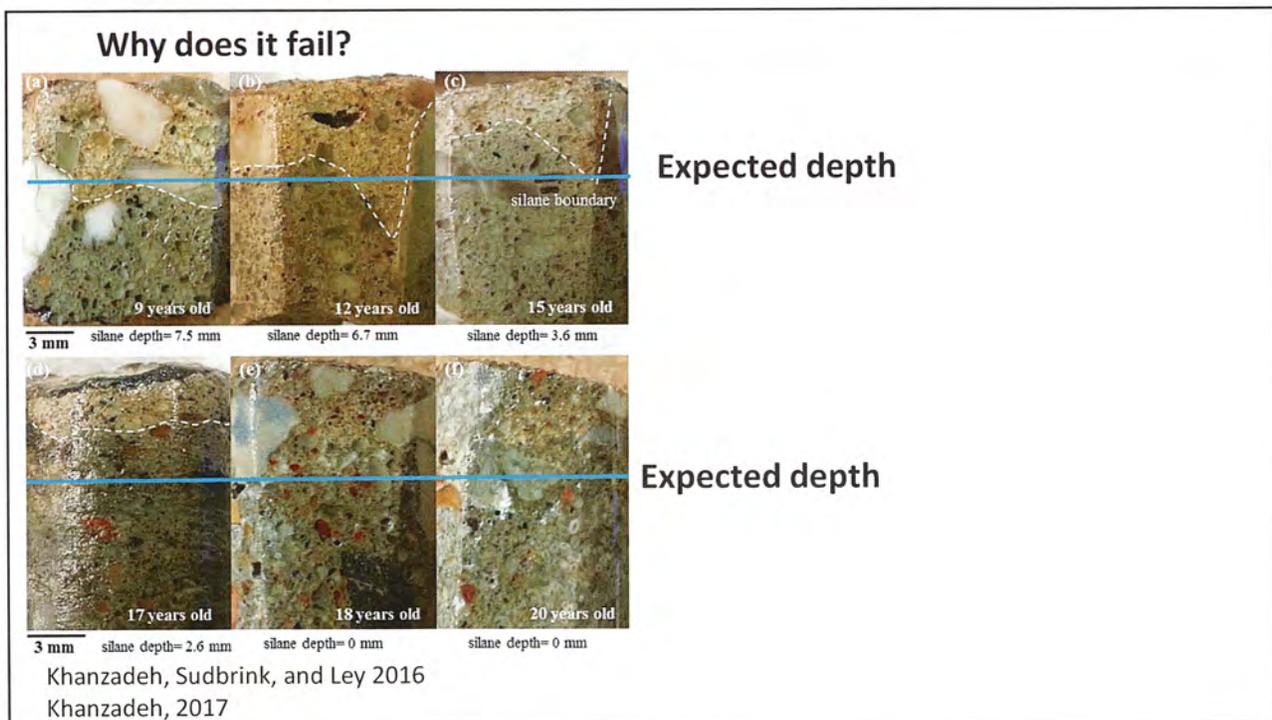
Travel Lane 100% | 67% | 21%

Shoulder 100% | 67% | 16%

Khazadeh, Sudbrink, and Ley 2016

Khazadeh, 2017

**40% solids content silane lasts
12 years in Oklahoma bridge decks
before the Silane starts to fail.**



Failure occurs from the bulk of the concrete as silane thins towards the surface and is likely caused by high pH in the pore solution. Deterioration appears to be related to the alkaline pore solution.



Silane in
pores



Concrete
pore solution

What can you do after it fails?

- You can apply it again!
- Warning! It may be harder to get the silane in mature concrete.

ODOT is changing their specifications from 40% silane to 100% silane.

Contracts are being let to recoat structures after 10y.

Conclusions

- **Coatings are a useful tool to extend the life of concrete structures.**
- **Not all coatings are created equal!**
- **Oklahoma DOT has a 40 Year history with successful application of silanes to extend the service life of structures.**

Conclusions:

- Silane can reduce chloride penetration over typical concrete.
- Silane penetration increases from 3d to 7d
- 100% solid content silane performed better than 40% solid content
- 100% solids silanes can penetrate small cracks (0.003") and penetrate the concrete ≈ 0.010 ".

www.youtube.com/tylerley

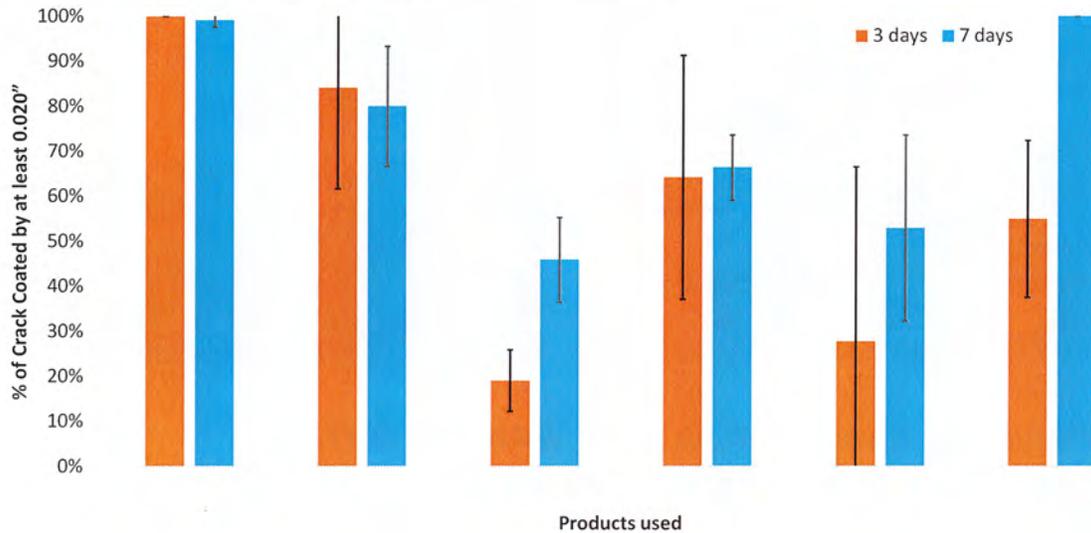




Silane plus Epoxy, can be done with one Surface Preparation (proprietary product)



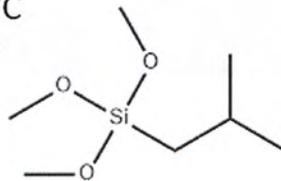
Results – Coating of the crack



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Isobutyl trimethoxysilane

- Molecular Formula: $C_7H_{18}O_3Si$
- Formula Weight: 178.3
- Density: 0.93 g/ml at 25 °C
- Flash point: 103 °F
- Chemical Structure:

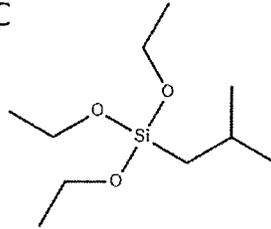


Source: National Institute of Standards and Technology.

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Triethoxyisobutylsilane

- Molecular Formula: $C_{10}H_{24}O_3Si$
- Formula Weight: 220.38
- Density: 0.88 g/ml at 25 °C
- Flash point: 138 °F
- Chemical Structure:



Source: United States Environmental Protection Agency.

- Triethoxyisobutylsilane is larger in size than Isobutyl trimethoxysilane which might affect the penetration of the products into the cracks

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