Why Do You Lose Air Volume When Pumping Air-Entrained Concrete??? *and Why Does the Air Come Back?*

Justin Becker, Nick Seader, Chad Staffileno
Tyler Ley, PE, PhD,

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Why I do what I do

I believe concrete is the greatest material in the world.

I want to make concrete more durable, economical, constructible, and sustainable.

I help build people and tools to make the concrete industry better.

2

Acknowledgements

- Oklahoma DOT
- FHWA
- Colorado DOT
- Kansas DOT
- Nebraska DOT
- Iowa DOT
- Minnesota DOT
- Idaho DOT
- North Dakota DOT
- Pennsylvania DOT
- Connecticut DOT
- Illinois DOT
- Indiana DOT
- Michigan DOT
- Wisconsin DOT
- New Jersey DOT
- RMC Foundation
- American Concrete Pumping Association

3

Acknowledgements

- Vermont DOT
- Jim Wild
- Justin LaRoche

4

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Overview

Why do we add air to concrete?
Why do pumps change the air content of concrete?
Why does the air come back?

If you see Pistol Pete then that means that something is very important!!!!

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Why is this important?

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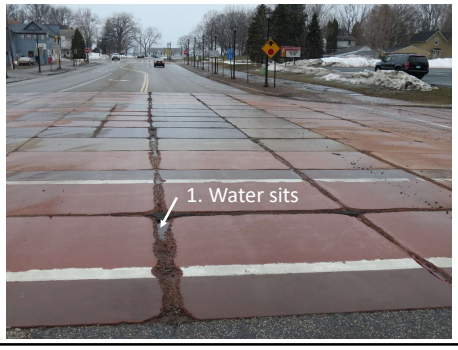

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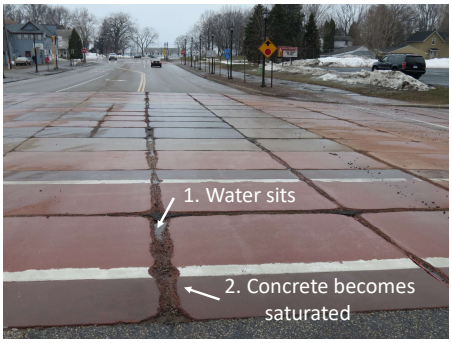

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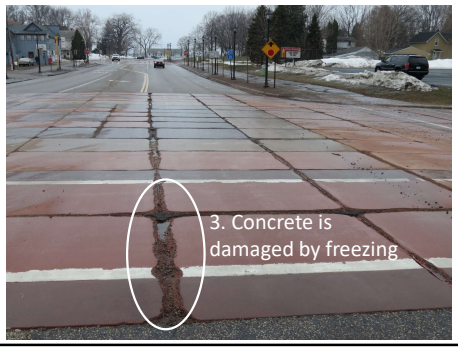

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Why is this happening?

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Why is this happening?

- Air void system
- Permeability – water to cement ratio
- Saturation level - environment

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Why is this happening?

- **Air void system**
- Permeability – water to cement ratio
- Saturation level - environment

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Why Do We Add Air to Concrete?

Air-entrained bubbles are a key to the freeze-thaw resistance of concrete

Air volume ≠ freeze-thaw performance

Smaller bubbles are more effective in providing freeze-thaw resistance and have less of an impact on our concrete than larger bubbles

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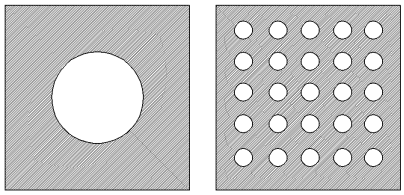
What Do You Want in an Air-Void System?

A B



- Volume of air provided is the same for both.
- Case B has a better air void distribution.

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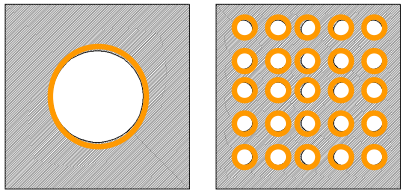
What Do You Want in an Air-Void System?

A B



- Volume of air provided is the same for both.
- Case B has a better air void distribution.

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AASHTO PP84

Freeze Thaw Field Acceptance

Air Volume ≥ 4%
SAM Number ≤ 0.30

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AASHTO PP84

Freeze Thaw Field Acceptance

Air Volume ≥ 4%

SAM Number ≤ 0.30

Where is this from?

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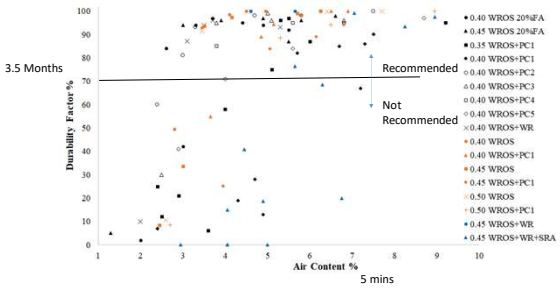
What air content do you use?



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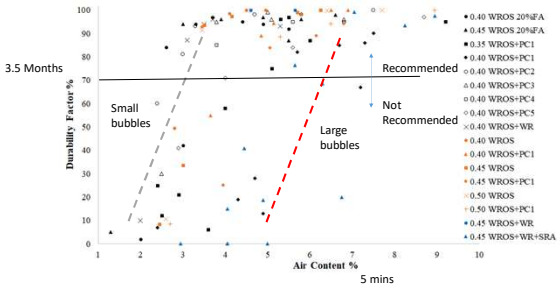
What air content do you use?



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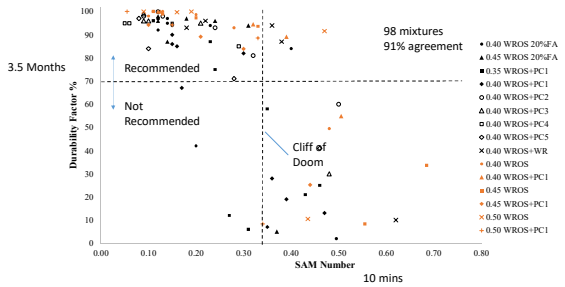

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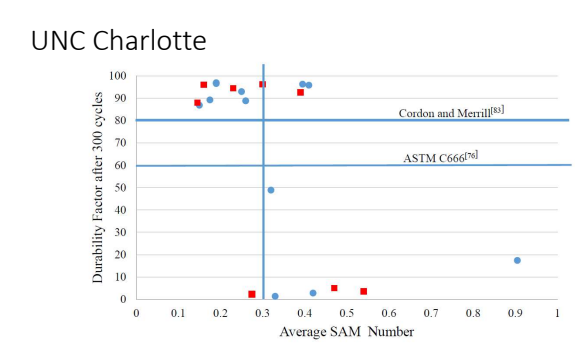

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Discussion

The SAM Number can better predict freeze thaw performance than the air volume.

The SAM Number can be determined in fresh concrete in about 10 mins.

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Why are we doing this?

Concrete pumps are essential tools in the industry but it is hard to predict how pumping will impact the air void system in concrete.

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When you pump air entrained concrete one of three things will happen:

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When you pump air entrained concrete one of three things will happen:

1. The air volume will go down

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When you pump air entrained concrete one of three things will happen:

1. The air volume will go down
2. The air volume will go up

28

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When you pump air entrained concrete one of three things will happen:

1. The air volume will go down
2. The air volume will go up
3. The air volume will stay the same

- Ken Hover

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When you pump air entrained concrete one of three things will happen:

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- Ken Hover

Engineers are worried about this and so it is common to require sampling after the concrete pump.

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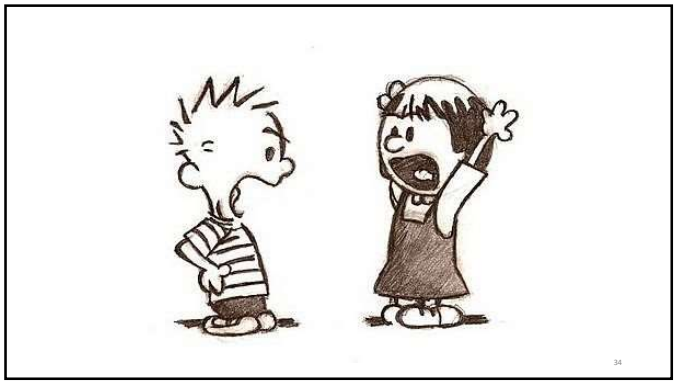

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How do people deal with this?

Increase the air volume before it goes into the pump so that it still has enough air when it comes out.

One time this worked….

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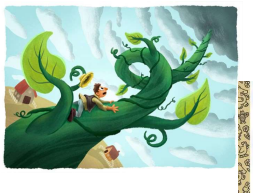

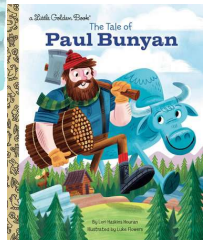

Durable asphalt

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Mechanisms

How does pumping change air?

1. Pressure

2. Vacuum

3. Impact

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Mechanisms

How does pumping change air?

1. Pressure

2. Vacuum

3. Impact

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Methods

- Investigate the following before and after pumping:

- Air volume
- SAM Number (air void spacing) AASHTO TP 118
- Spacing factor (air void spacing) ASTM C 457
- Freeze-thaw performance ASTM C 666

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Mixture Design

- 0.45 w/cm
- 20% Class C ash
- 6.5 sacks (611 lbs)
- Limestone and natural sand
- 5” to 8” slump

Air contents from 4% to 8%
With and without water reducer/retarder
33 lab mixtures

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Pipe Network

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Lab Pumping Information

- 4" diameter pipe
- 60' of steel pipe
- 10' Rubber hose
- pumping pressures from 55 to 110 psi

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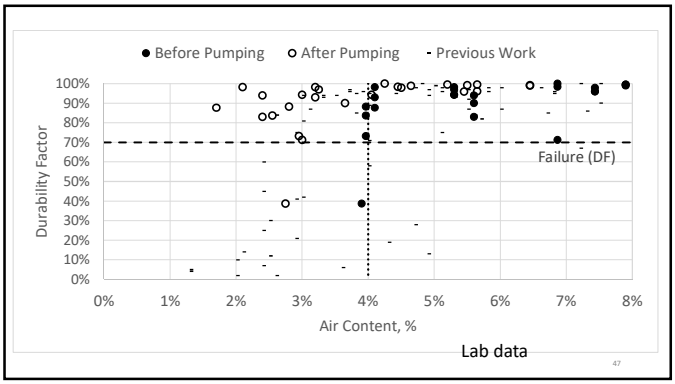

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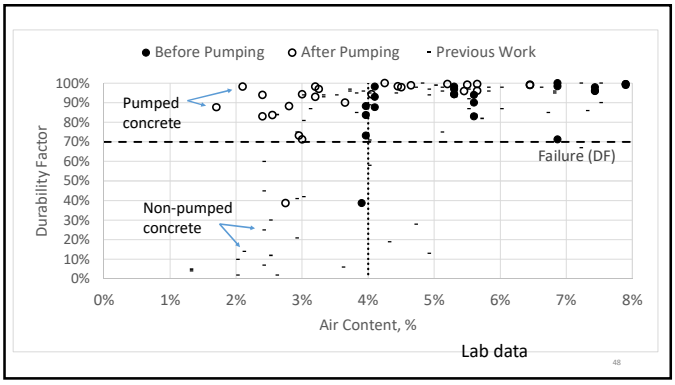

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Summary

Before Pumping	After Pumping	Hardened Concrete
33		
Fresh Air > 4.0% SAM # < 0.32		

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Summary

Before Pumping	After Pumping	Hardened Concrete
33 →	11	
Fresh Air > 4.0% SAM # < 0.32	Fresh Air > 4.0% SAM # < 0.32	

Fresh Air < 4.0%
SAM # > 0.32

50

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Summary

Before Pumping	After Pumping	Hardened Concrete
33 →	11 →	33
Fresh Air > 4.0% SAM # < 0.32	Fresh Air > 4.0% SAM # < 0.32	ASTM C666 Durability Factor > 70%

Fresh Air < 4.0%
SAM # > 0.32

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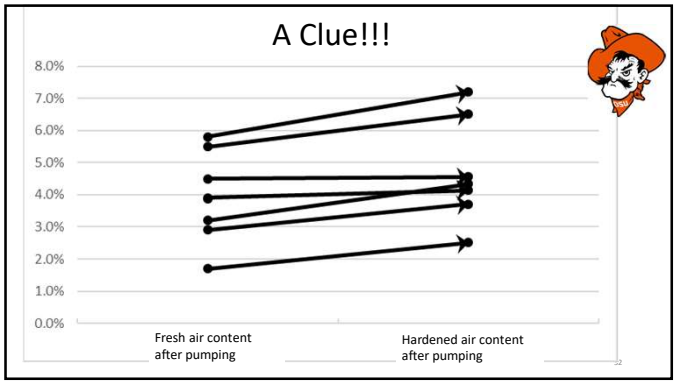
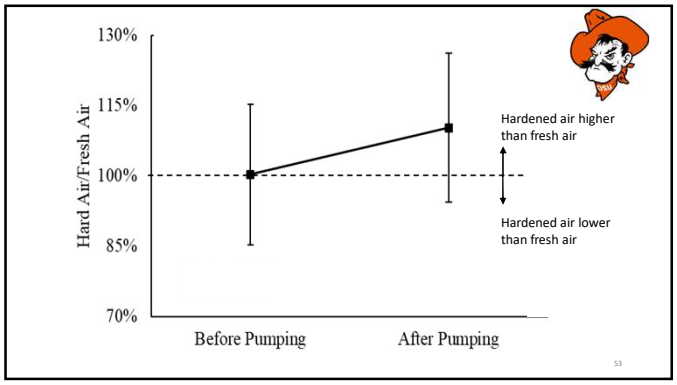

A Clue!!!
8.0%
7.0%
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
0.0%
Fresh air content after pumping
Hardened air content after pumping

52


130%
115%
100%
85%
70%
Hard Air/Fresh Air
Hardened air higher than fresh air
Hardened air lower than fresh air
Before Pumping
After Pumping

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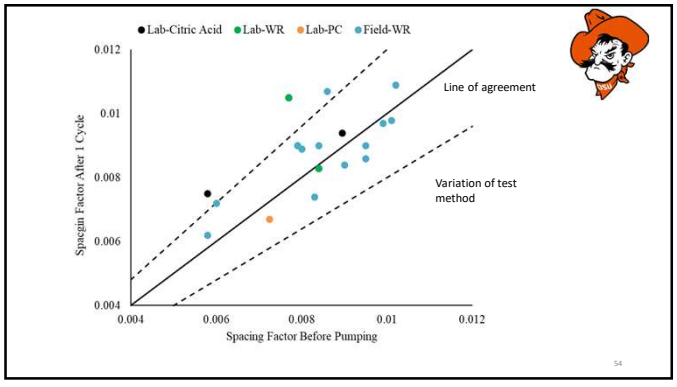
Lab-Citric Acid
Lab-WR
Lab-PC
Field-WR
0.012
0.01
0.008
0.006
0.004
Spacgin Factor After 1 Cycle
Line of agreement
Variation of test method
0.004
0.006
0.008
0.01
0.012
Spacing Factor Before Pumping

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Discussion

- Satisfactory freeze thaw performance of pumped concrete was observed even though there were low air contents and high SAM Numbers after pumping.
- BUT! There is minimal change in the spacing factor measured on the hardened concrete taken before and after pumping.

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Discussion

- The hardened and fresh measurements closely matched prior to pumping.
- After pumping the hardened air content was on average 1.15x higher in the fresh air content.

For example – After pumping 6% fresh and about 7% in hardened concrete

The fresh measurements after pumping do not represent the performance or properties of the hardened concrete.

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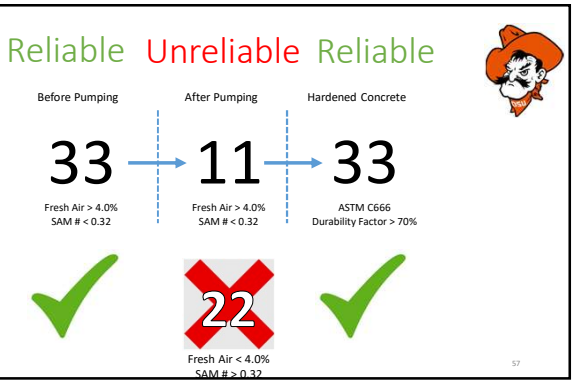

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Does this hold for other equipment and mixtures?

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Field Pumping Information

- 62 different mixtures tested
- 30+ different projects
- Bridge decks, walls, sidewalk, parking lot, drilled shaft
- 18 Different Types of Pumps
- Boom lengths ranged from 100’ to 180’
- Pipes from 4” to 6” in diameter
- Used three different boom configurations

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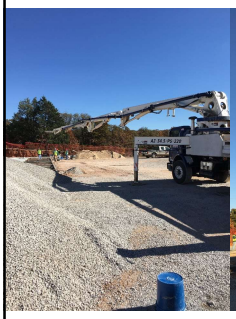
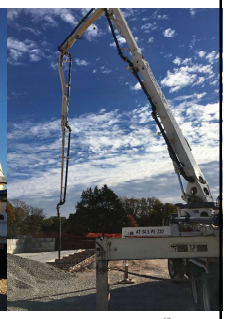
Flat | Arch | A-Frame





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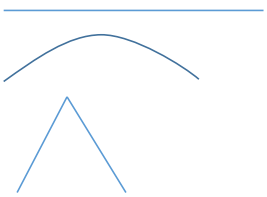
Pump configurations



Flat

Arch

A-frame

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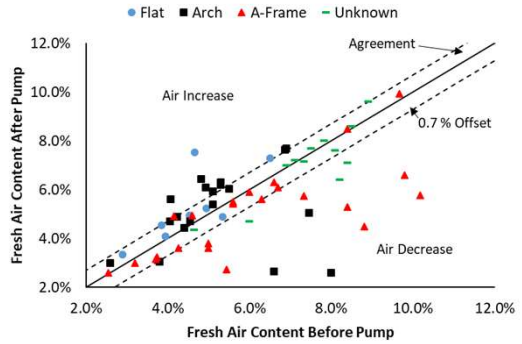

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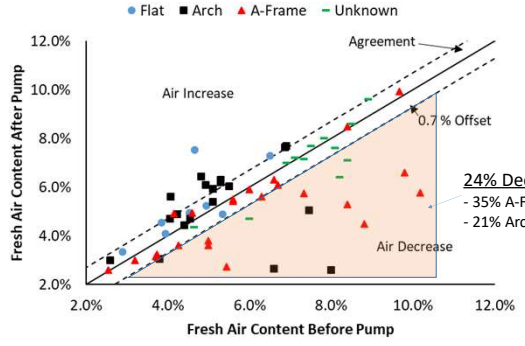

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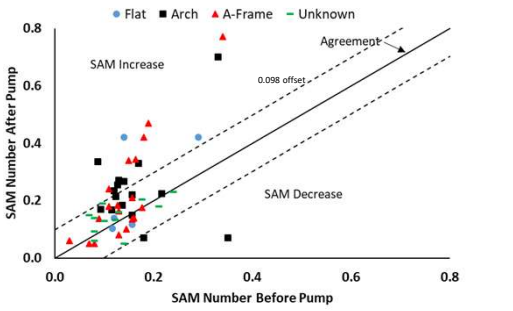

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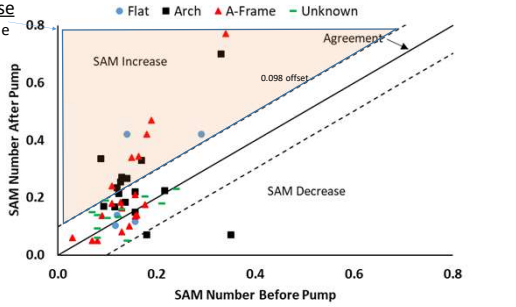

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Discussion

- Air Content
  - 24% of samples show a significant decrease
  - A-frame caused the most impact on the air volume after pumping
- SAM Number
  - 29% of samples increased significantly
  - Arch configuration caused the most impact on void spacing after pumping

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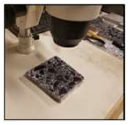
How about the hardened concrete?



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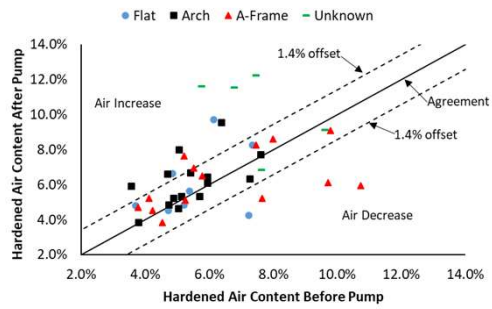

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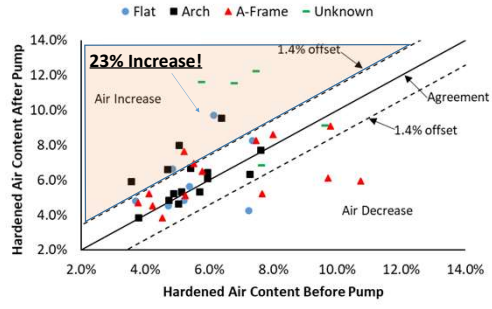

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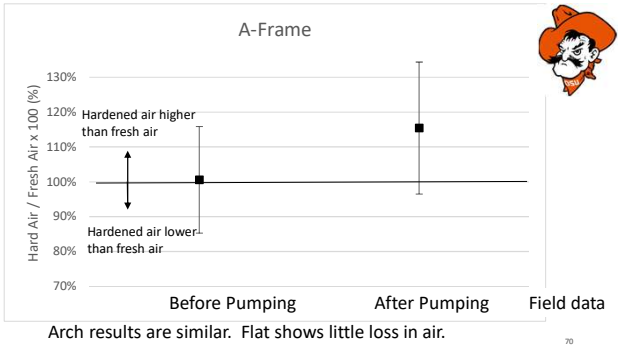

Arch results are similar. Flat shows little loss in air.

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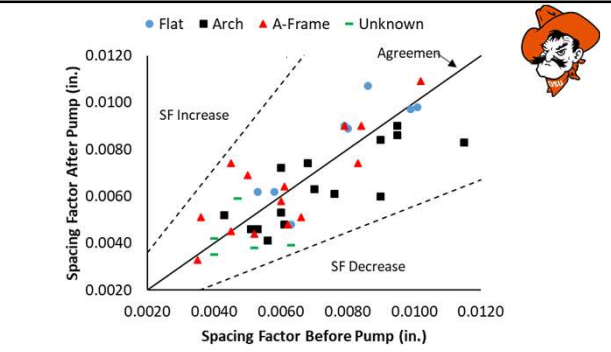

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Discussion

- The hardened and fresh measurements closely matched prior to pumping.
- After pumping the hardened air content was on <u>average</u> 1.15x higher than the fresh air content.

For example – After pumping 6% fresh and about 7% in hardened concrete

- There is no significant change in the spacing factor when comparing data before and after pumping.

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Discussion

These are the same findings from the lab but with different pump configurations, equipment, and materials!!!!

The fresh measurements after pumping do not seem to represent the performance or properties of the hardened concrete.

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What is happening?

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Where does the air change within the pump network?

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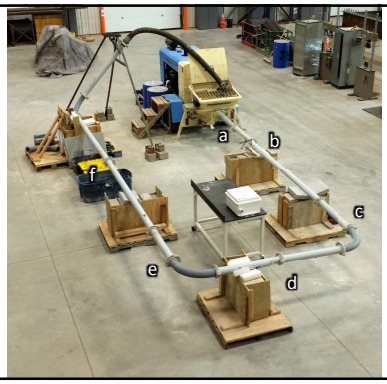

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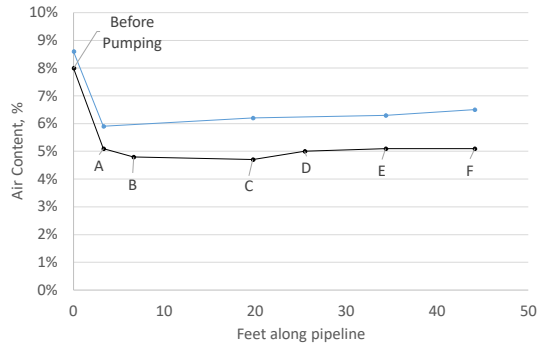

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Discussion

The air is lost right after the pump and stays almost constant throughout the pipe network.

Additional piston strokes (pressure cycles) did not cause additional air to be lost.

The air loss coincides with point of highest pressure.

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Why does this happen?

Henry's Law – p=kc

- p=partial pressure of the gas
- c=concentration of the dissolved gas in solution
- k=constant

↑ Pressure
↑ Dissolved gas

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How does this change the bubble size distribution?

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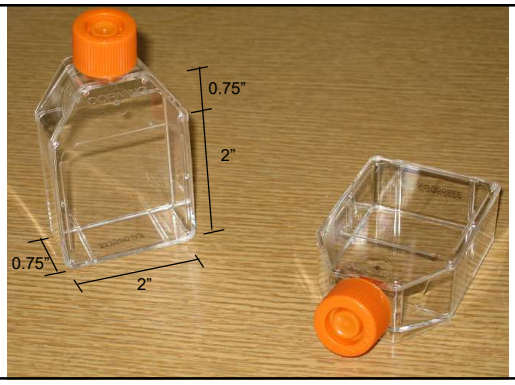

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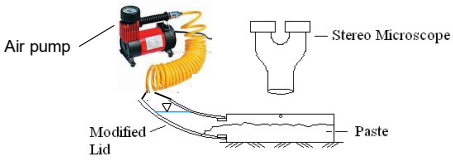
Air pump
Stereo Microscope
Modified Lid
Paste

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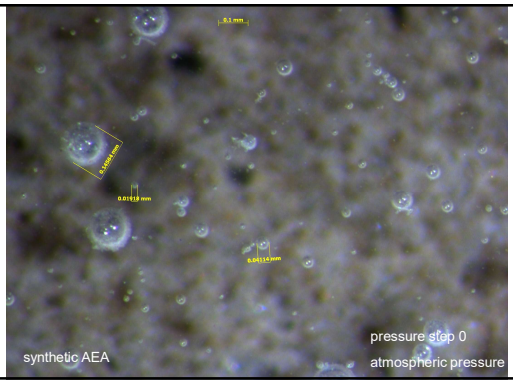
synthetic AEA
pressure step 0
atmospheric pressure

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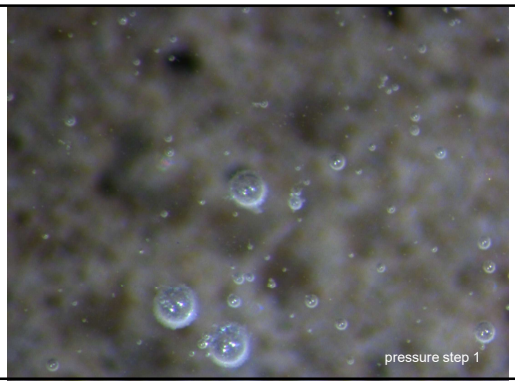

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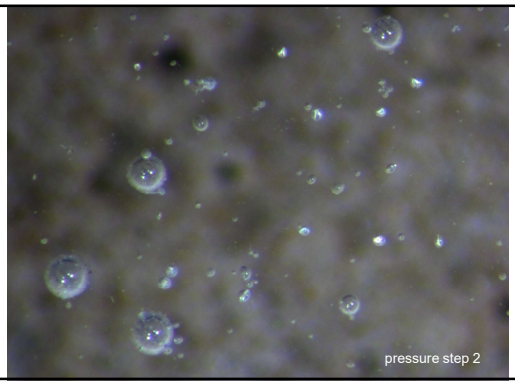

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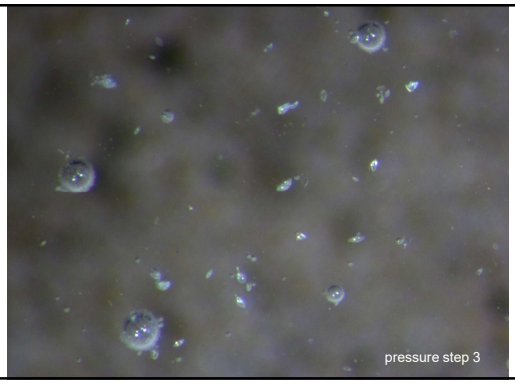

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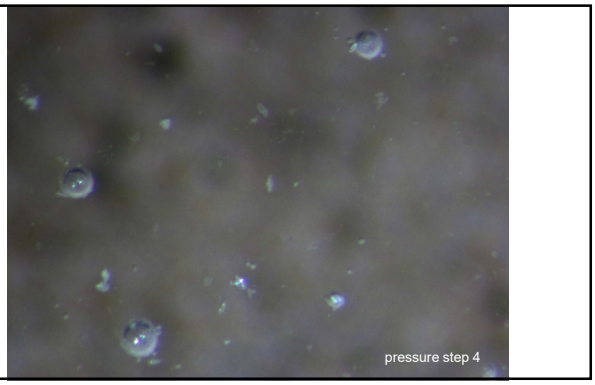

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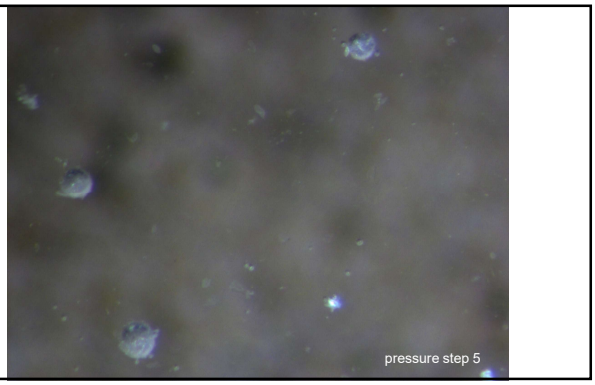

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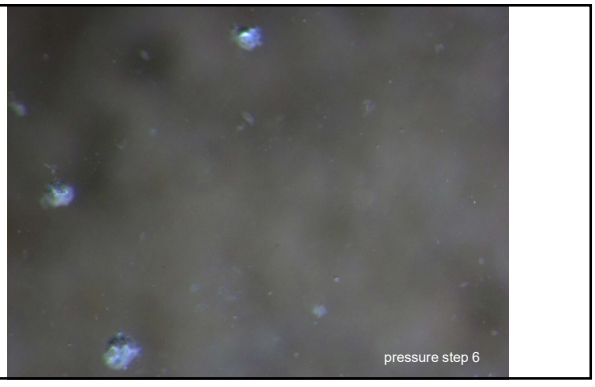

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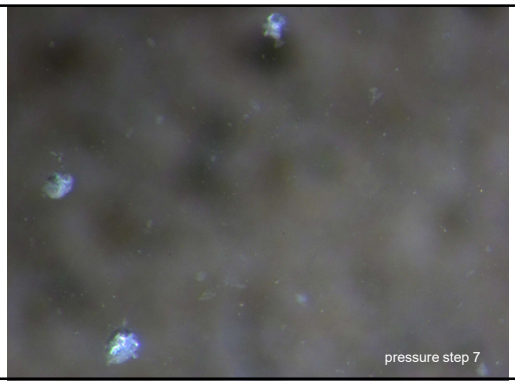
pressure step 7

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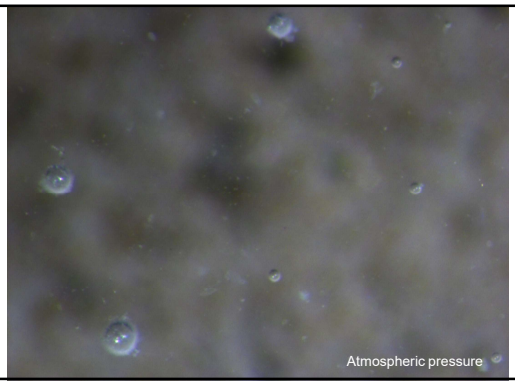
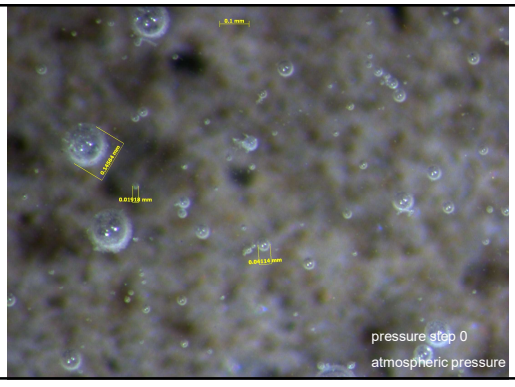

Atmospheric pressure

92


pressure step 0
atmospheric pressure

93

Discussion

1. As the pressure increases the small bubbles dissolve into the surrounding solution

2. These bubbles do not immediately come back when you decrease the pressure.

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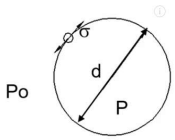
Why do the small bubbles dissolve???

Laplace-Young Equation

$P_i = P_0 + 4\sigma/d$

- P_i=internal pressure of the air bubble
- P_0=pressure of fluid surrounding the bubble
- σ=surface tension of the bubble film
- d=bubble radius



This means the small bubbles have higher pressure than the large bubbles.

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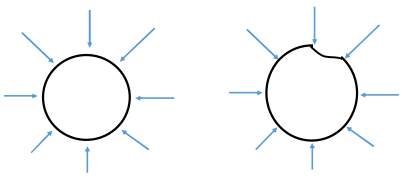
Why do the small bubbles dissolve???

- The small bubbles have a large curvature. This makes it easier for the bubble walls to become damaged and the air will dissolve.



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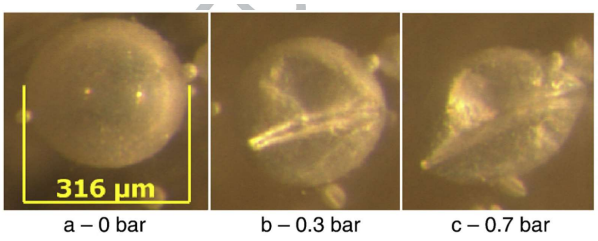

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What does this mean?

- The pressures during pumping causes the small bubbles to dissolve and so they are not present in the fresh concrete when it discharges from the pump.
- This is why the air volume decreases and the SAM Number increases.

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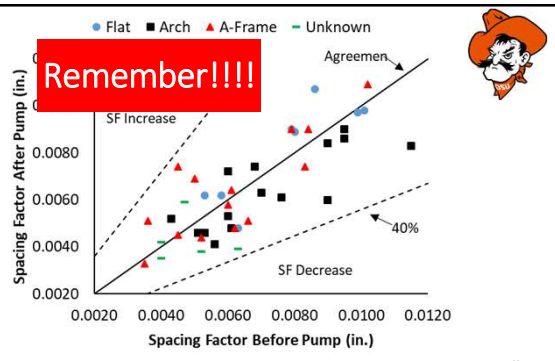

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Air and SAM over time

- We pumped concrete and measured how the air volume and SAM Number change over time.

Sampling time after pumping

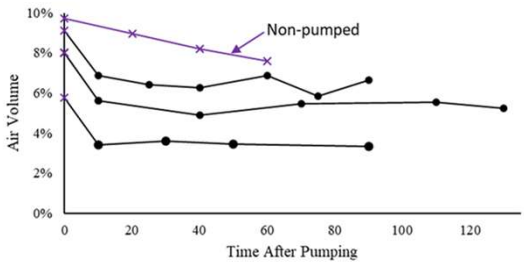
15 min

30 min

45 min

100

100



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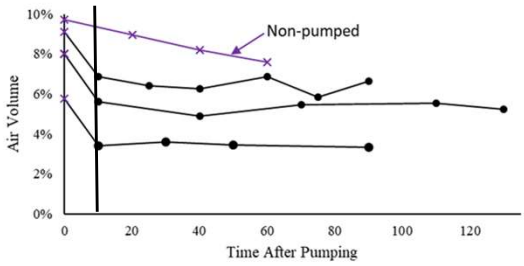

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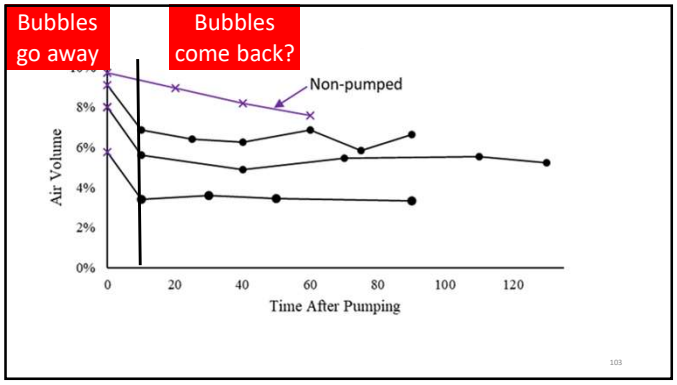
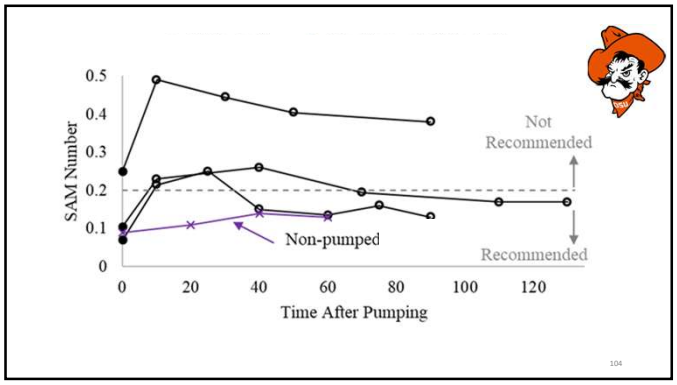
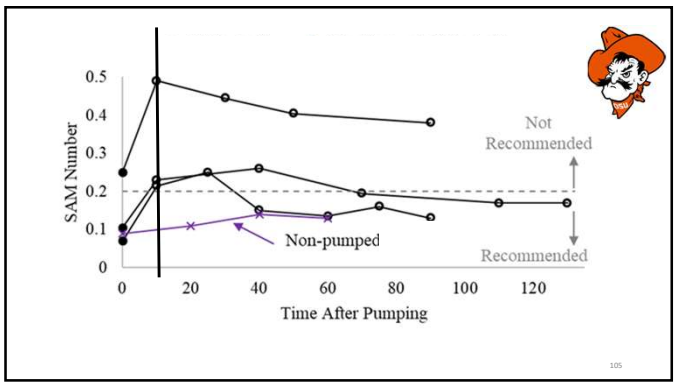

Bubbles go away
Bubbles come back?
Non-pumped
Air Volume
8%
6%
4%
2%
0%
0
20
40
60
80
100
120
Time After Pumping
103

103


SAM Number
0.5
0.4
0.3
0.2
0.1
0
Not Recommended
Recommended
Non-pumped
0
20
40
60
80
100
120
Time After Pumping
104

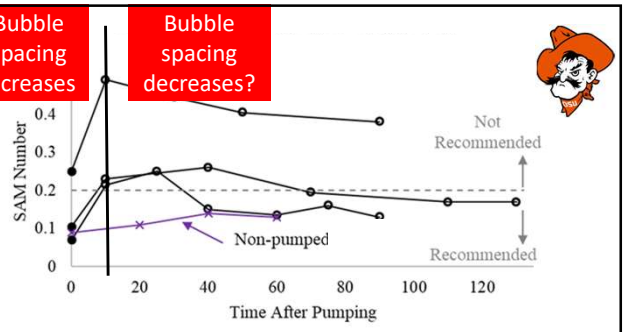
104


SAM Number
0.5
0.4
0.3
0.2
0.1
0
Not Recommended
Recommended
Non-pumped
0
20
40
60
80
100
120
Time After Pumping
105

105

Bubble spacing increases

Bubble spacing decreases?



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What is happening???

- The pressures from pumping causes the small bubbles to **temporarily** dissolve
- But good performance in the petrographic analysis, freeze-thaw testing, and reducing SAM Number over time suggests that the **dissolved air comes back before the concrete hardens**.
- When the air comes back it seems to be well dispersed and provides a similar spacing factor to what went into the pump.

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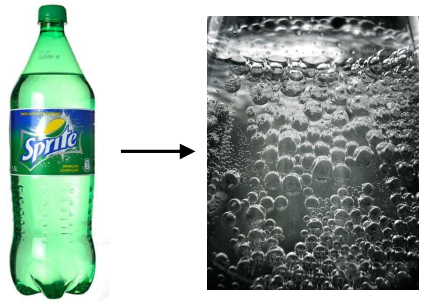

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What does this mean?

- **Air Content and SAM testing <u>after pumping</u> are not representative of the hardened concrete.**
- If this is true then concrete should not be rejected for low air or high SAM Number after pumping.
- It appears that sampling the concrete prior to pumping is a good indicator to the air void system in the hardened concrete.

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What do <u>I think</u> needs to happen?

- Testing air at the point of discharge from a pump is dangerous and it is not representative of the properties of the hardened concrete.
- We need to test concrete before pumping and not require testing at the point of placement.

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What do I think needs to happen?

- I think our air testing needs to be done with the SAM because it better correlates with freeze thaw performance.
- We need to have local discussions about how we need to change specifications and construction practices.

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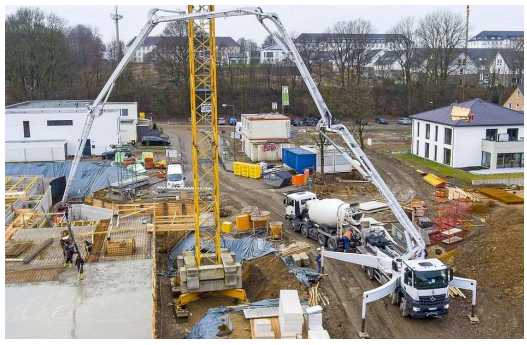

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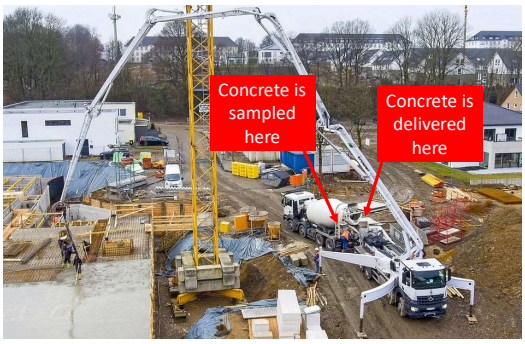

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Conclusion

- Pumping was observed to modify the air content and SAM Number in both the lab and the field testing.
- Based on the hardened air void analysis, freeze thaw testing, and changing SAM Number over time, the small bubbles seem to return to the concrete with a similar air void distribution and freeze thaw performance as was in the concrete before pumping.
- The SAM was an invaluable tool to give insights into the performance of air before and after a concrete pump.

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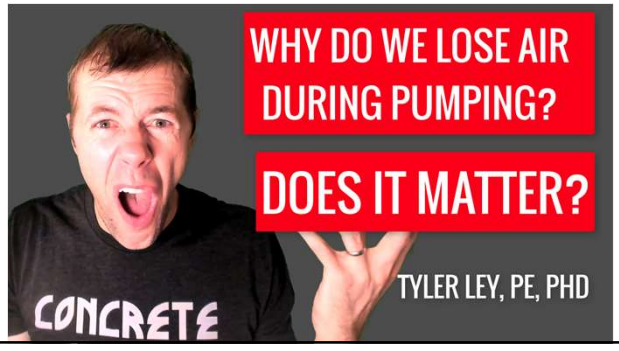
www.youtube.com/tylerley



123


STAR WARS
RETURN OF THE BUBBLES

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Questions?
www.tylerley.com
Tyler.ley@okstate.edu

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