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

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Acknowledgements

- Oklahoma DOT
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- Vermont DOT
- Jim Wild
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- Robert Conway

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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 Do We Add Air to Concrete?

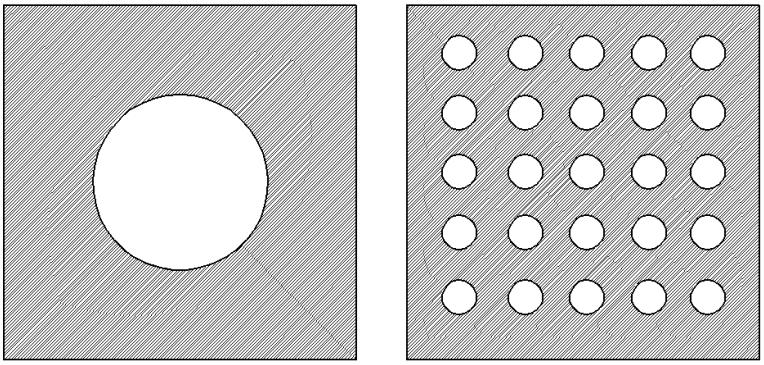
Air-entrained bubbles are a key to the freeze-thaw resistance of concrete

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

What Do You Want in an Air-Void System?

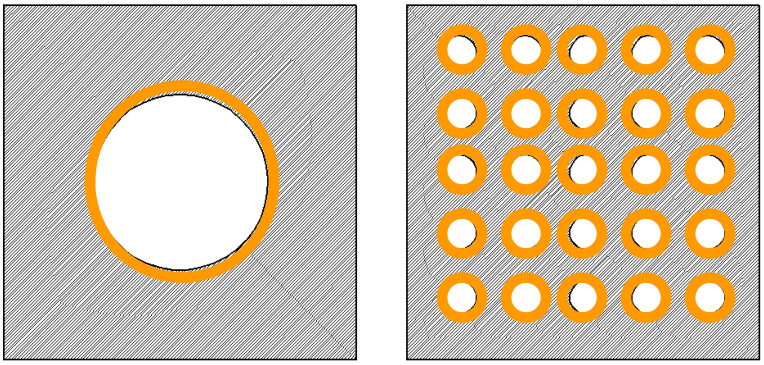
A B



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

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.

AASHTO R101

Super Air Meter
Freeze Thaw Field Acceptance

Air Volume ≥ 4%
SAM Number ≤ 0.30

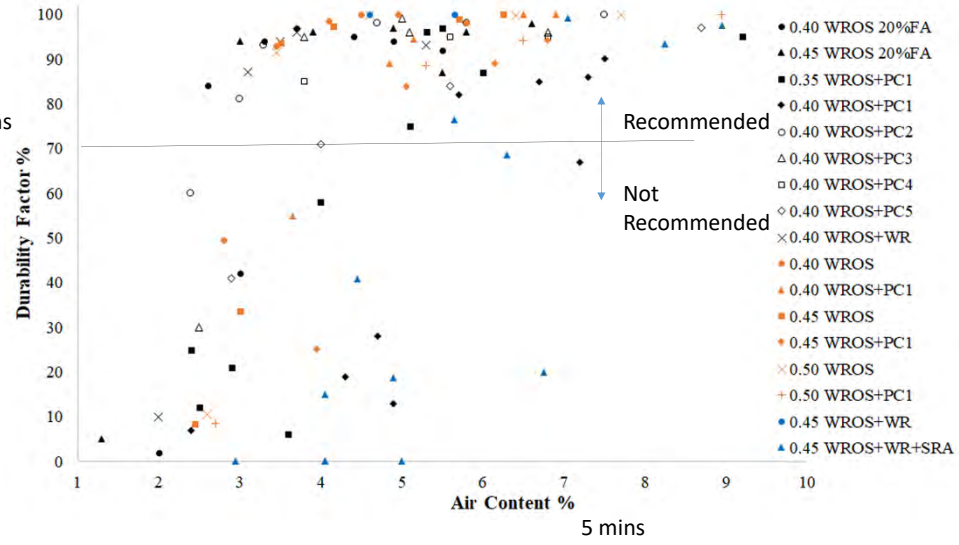
AASHTO R101

Super Air Meter
Freeze Thaw Field Acceptance

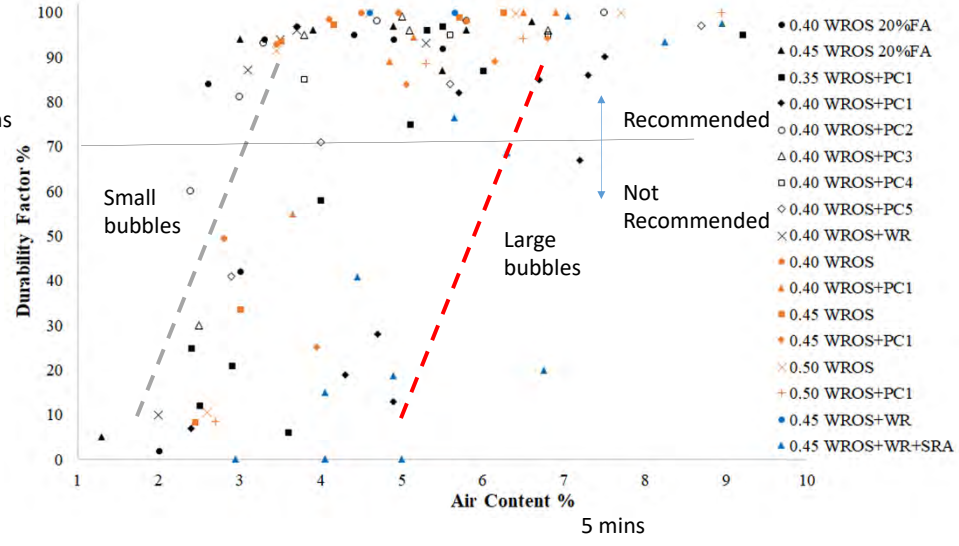
Air Volume ≥ 4%
SAM Number ≤ 0.30

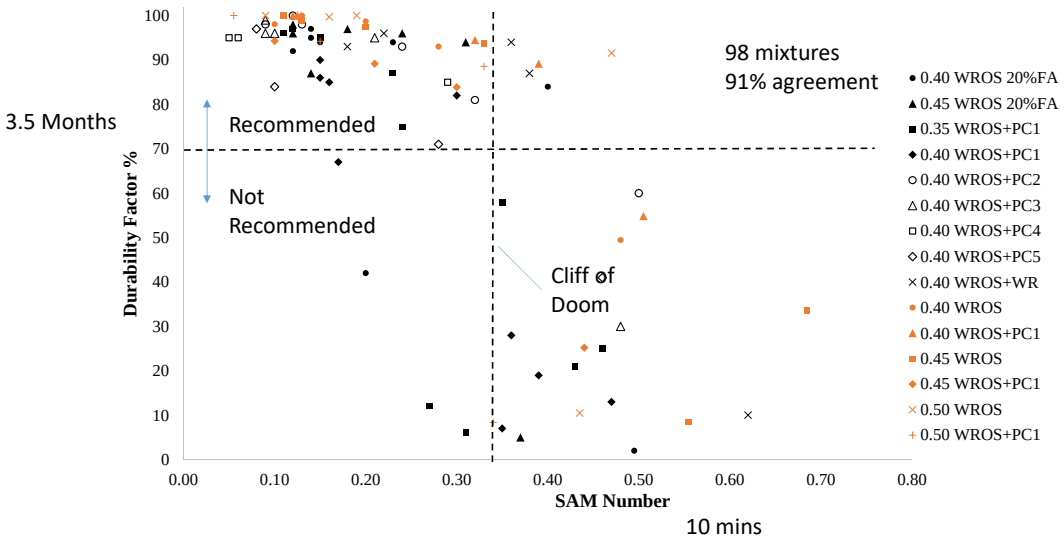
Where is this from?

What air content do you use?

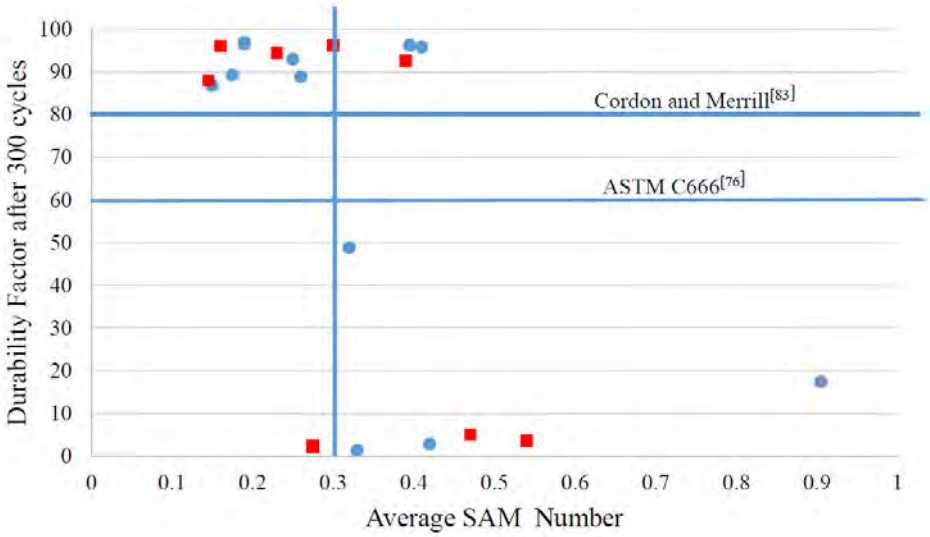


What air content do you use?





UNC Charlotte



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Discussion

Higher air content = Improved freeze thaw durability

Lower SAM Number = Improved freeze thaw durability

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

Both air volume and SAM Number can be measured in fresh concrete.

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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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Ready Mix
General Contractor
21


Ready Mix
I brought you concrete with the right air!
General Contractor
22

23

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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Mechanisms

How does pumping change air?

1. Pressure

2. Vacuum

3. Impact

25

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 T 395
- Spacing factor (air void spacing) ASTM C 457
- Freeze-thaw performance ASTM C 666

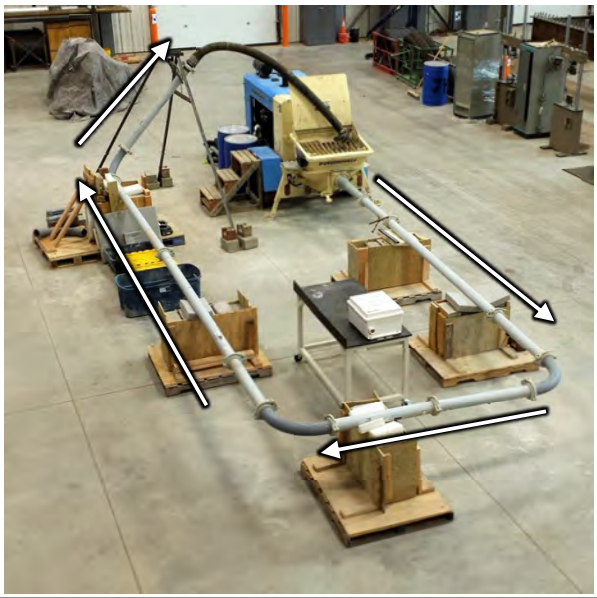
Mixture Design

- 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

29

Pipe Network



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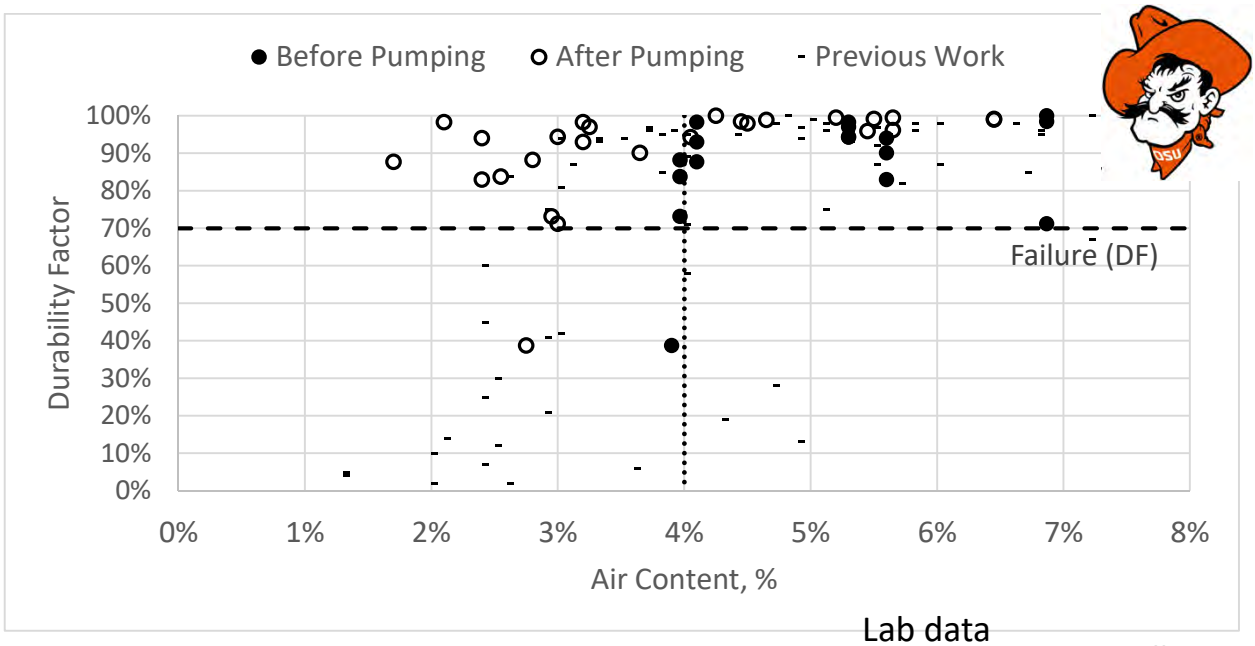
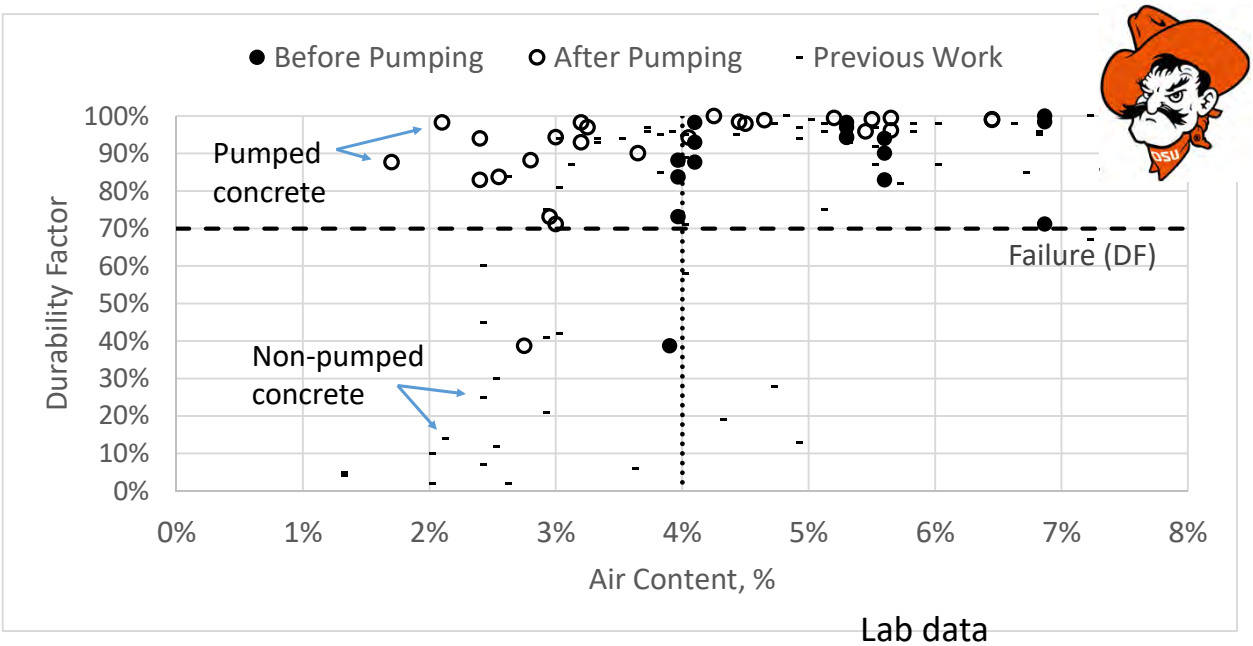
Lab Pumping Information

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



Lab data

32



Lab data

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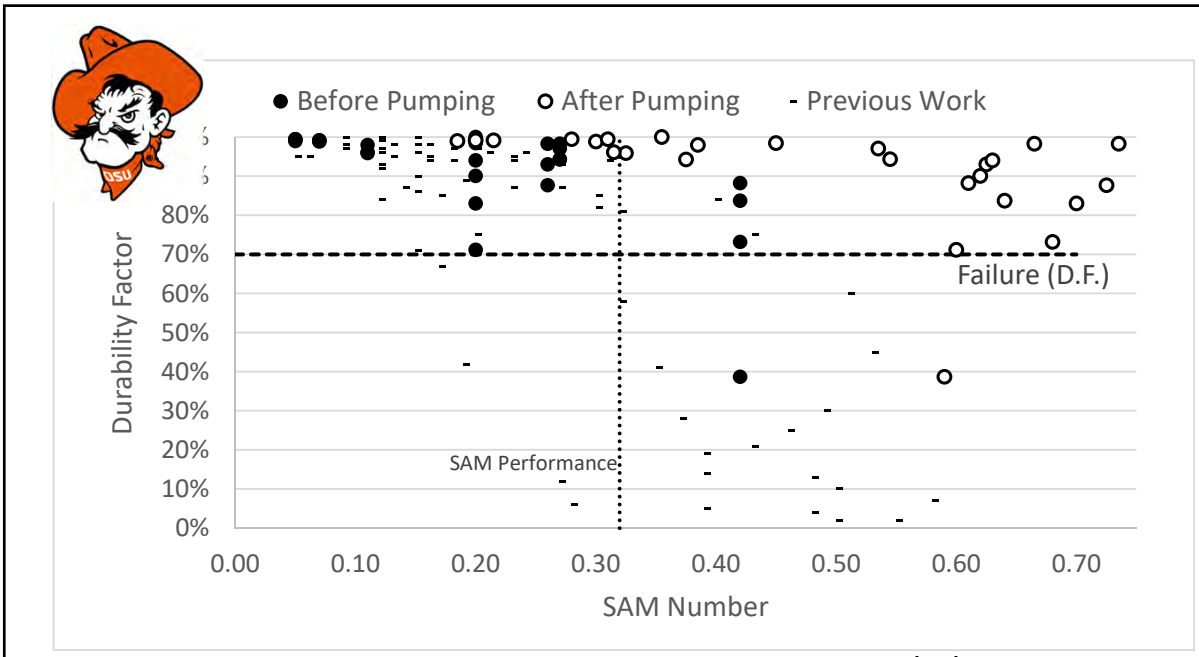

Lab data

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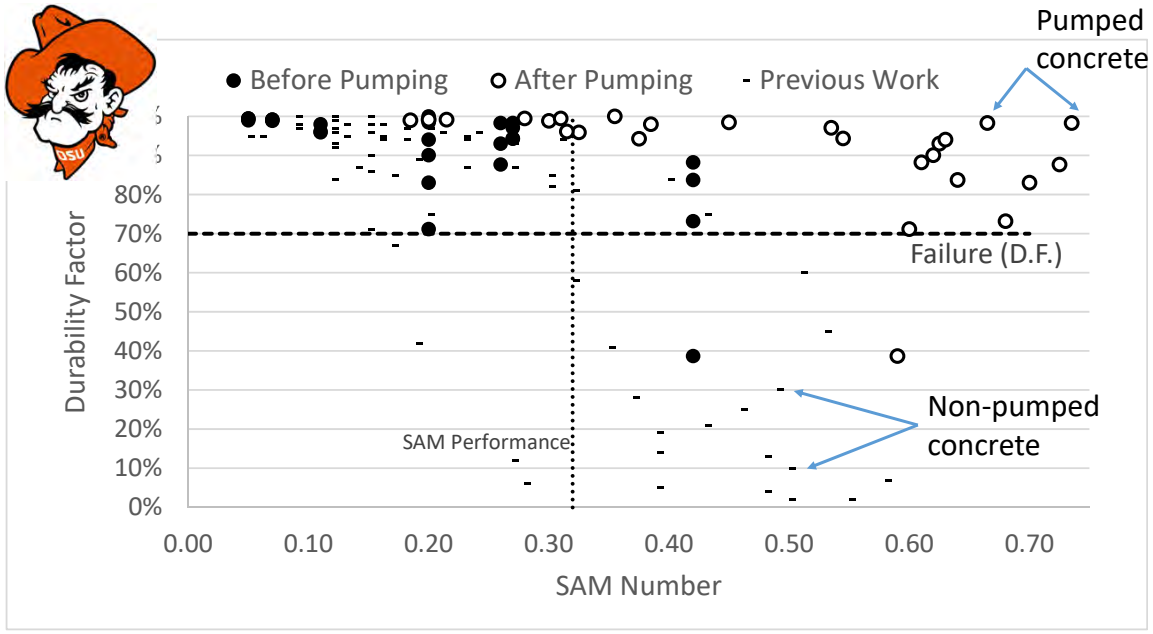

Lab data

35

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	
✓	22	
	Fresh Air < 4.0% SAM # > 0.32	

37

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%
✓	22	✓
	Fresh Air < 4.0% SAM # > 0.32	

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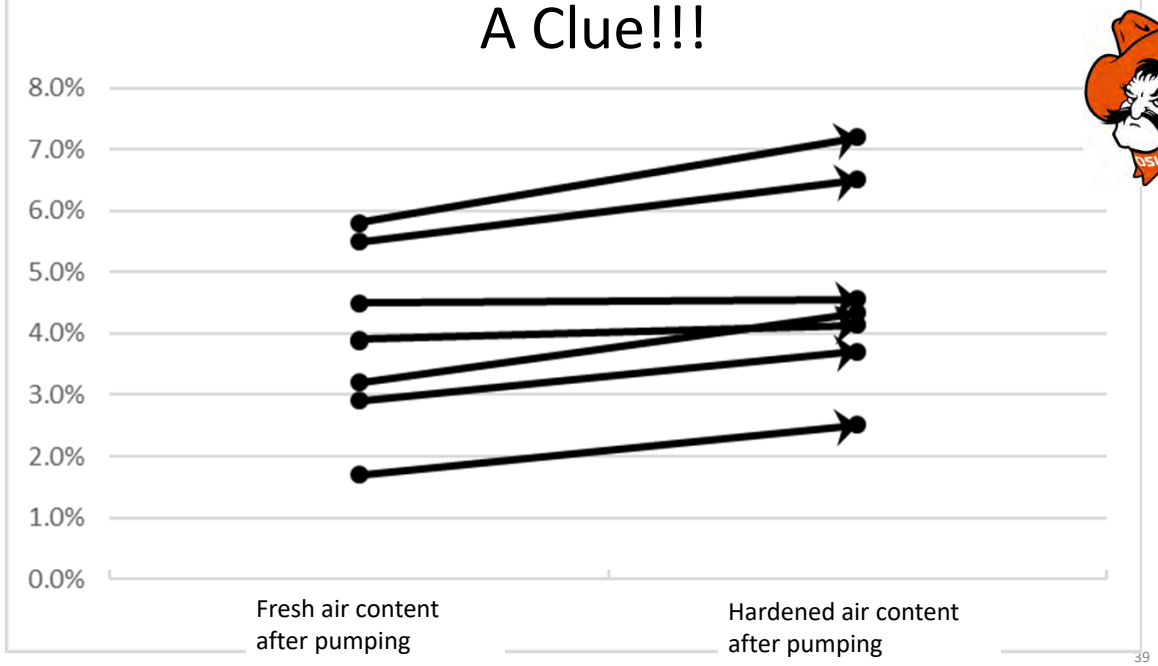
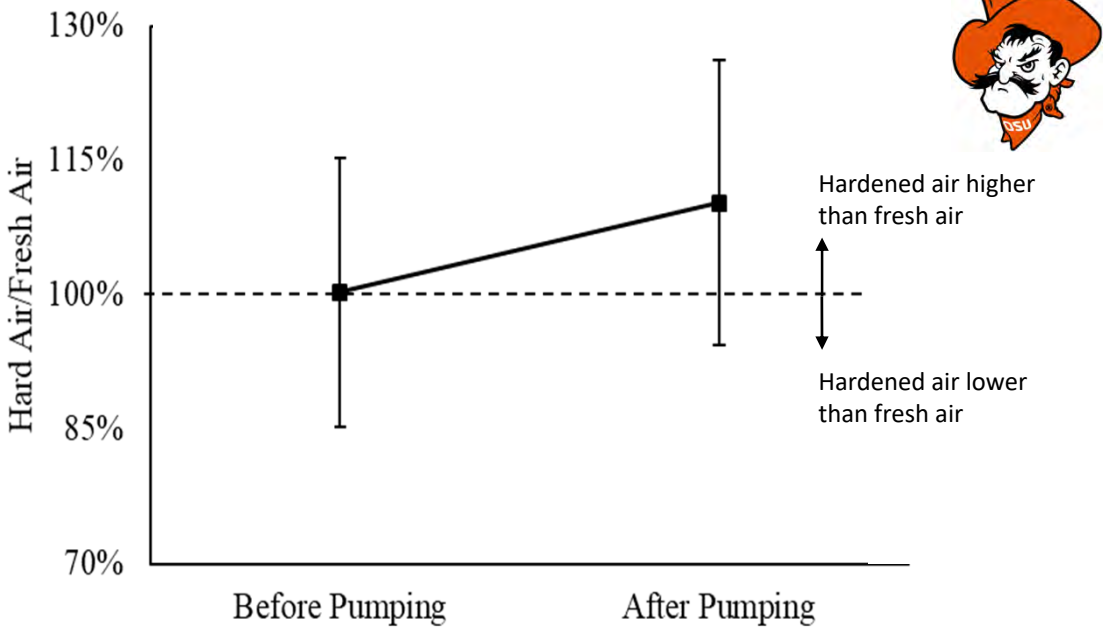
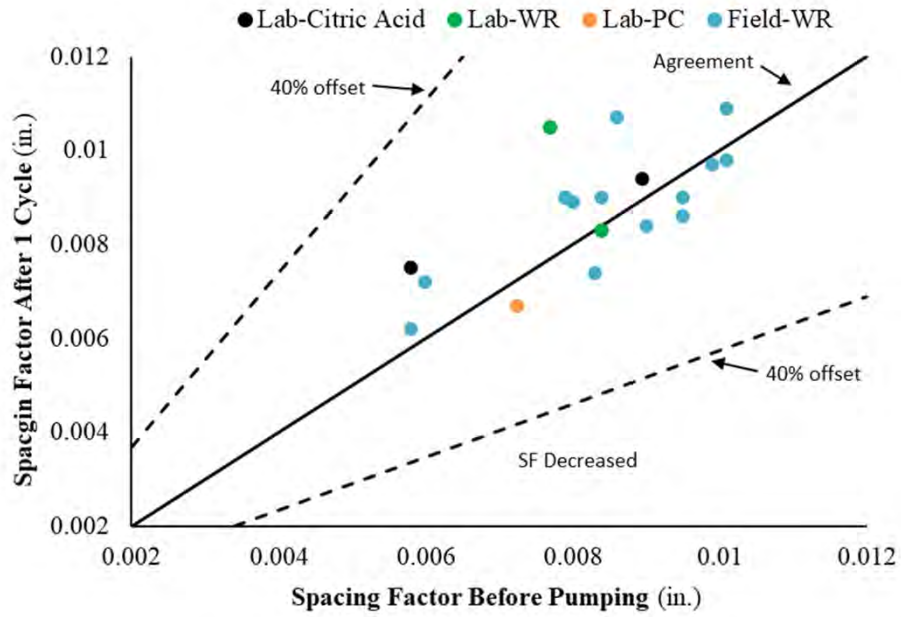
A Clue!!!


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

39


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

40



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.

42

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 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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Reliable Unreliable Reliable

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%
✓	22 ✗	✓

Fresh Air < 4.0%
SAM # > 0.32

44

Does temperature change the results?

We made concrete mixtures with either heated or cooled ingredients

Six cold mixes – 47°F avg (37°F to 53°F)

Five hot mixes – 102°F avg (98°F to 111°F)

Four room temp - 76°F

45

Does temperature change the results?

The same pump, pipe orientation, testing, and sampling procedures were used.

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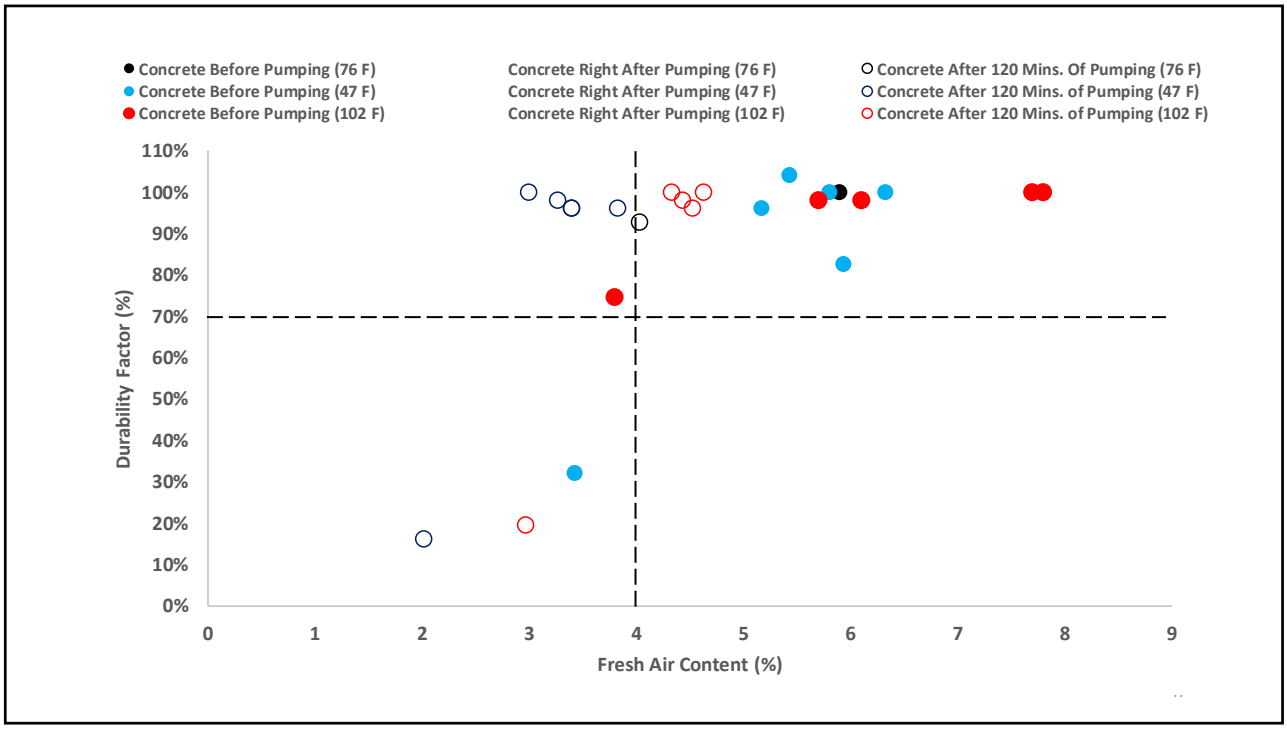
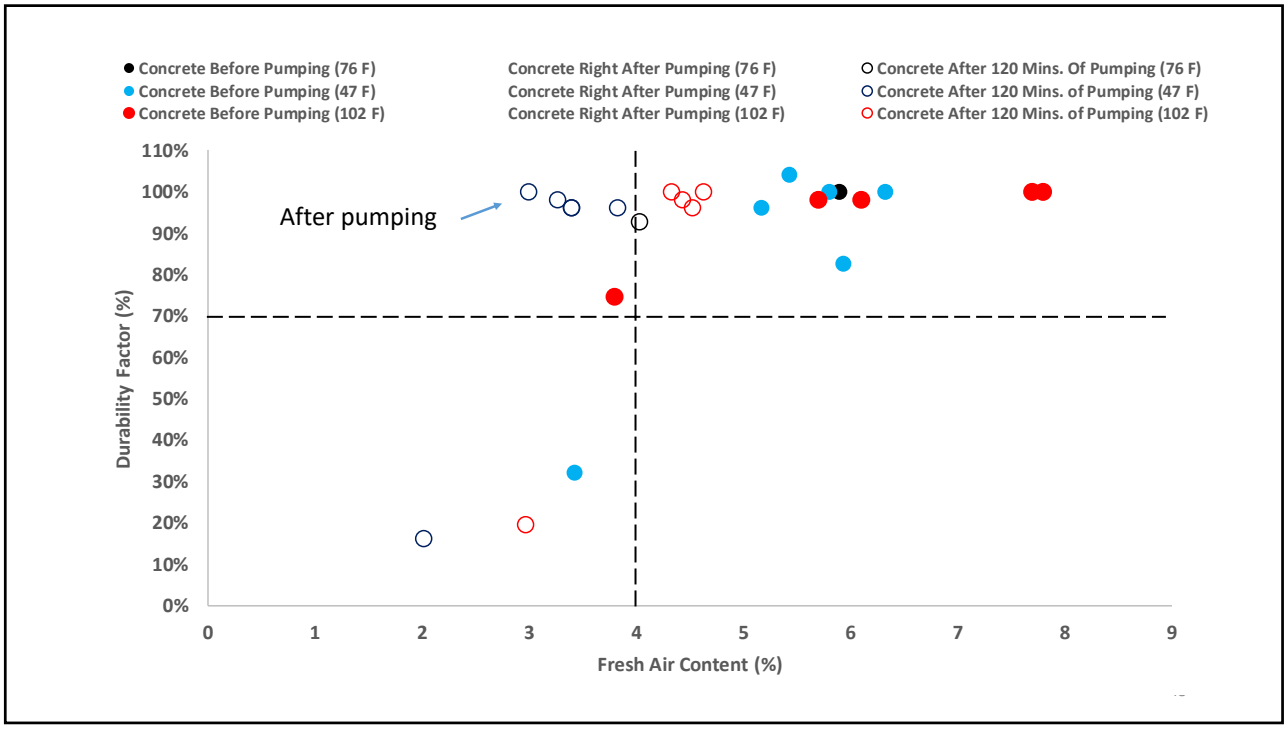

Concrete Before Pumping (76 F)
Concrete Before Pumping (47 F)
Concrete Before Pumping (102 F)
Concrete Right After Pumping (76 F)
Concrete Right After Pumping (47 F)
Concrete Right After Pumping (102 F)
Concrete After 120 Mins. Of Pumping (76 F)
Concrete After 120 Mins. of Pumping (47 F)
Concrete After 120 Mins. of Pumping (102 F)
Durability Factor (%)
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
6
7
8
9
Fresh Air Content (%)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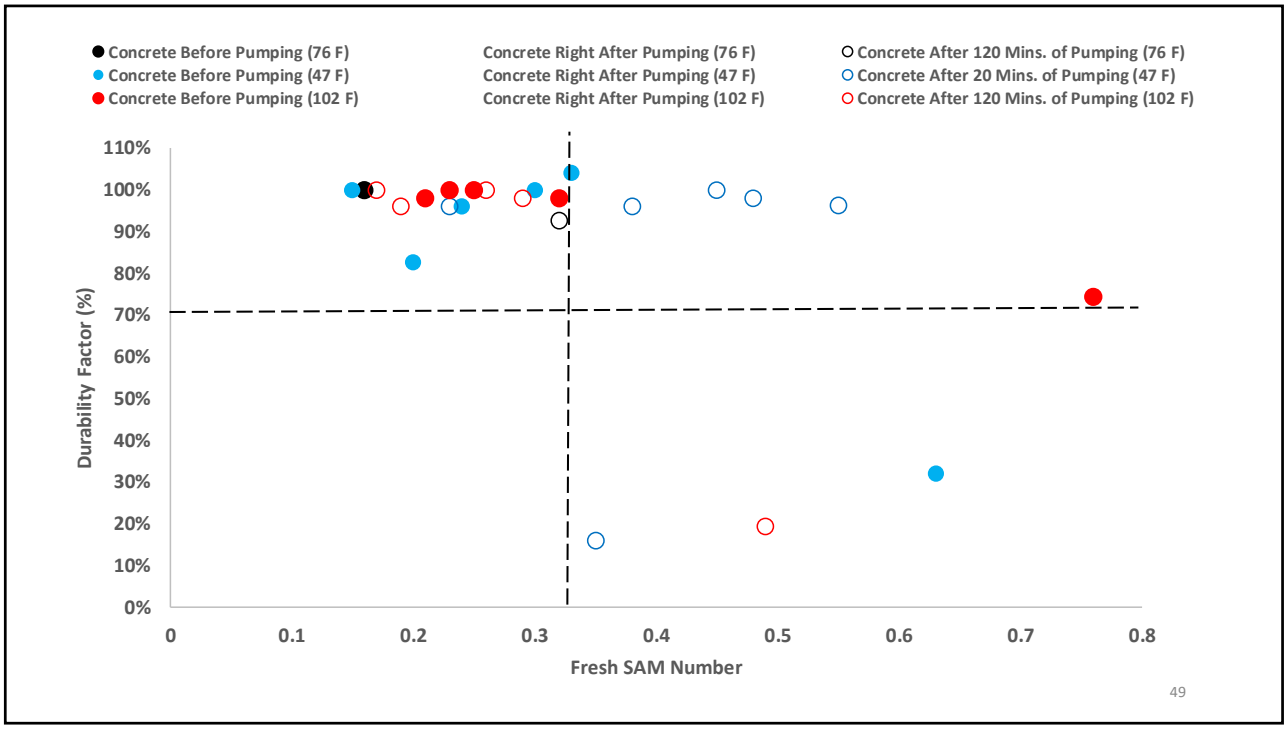
Concrete Right After Pumping (47 F)
Concrete Right After Pumping (102 F)
Concrete After 120 Mins. Of Pumping (76 F)
Concrete After 120 Mins. of Pumping (47 F)
Concrete After 120 Mins. of Pumping (102 F)
After pumping
Durability Factor (%)
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
1
2
3
4
5
6
7
8
9
Fresh Air Content (%)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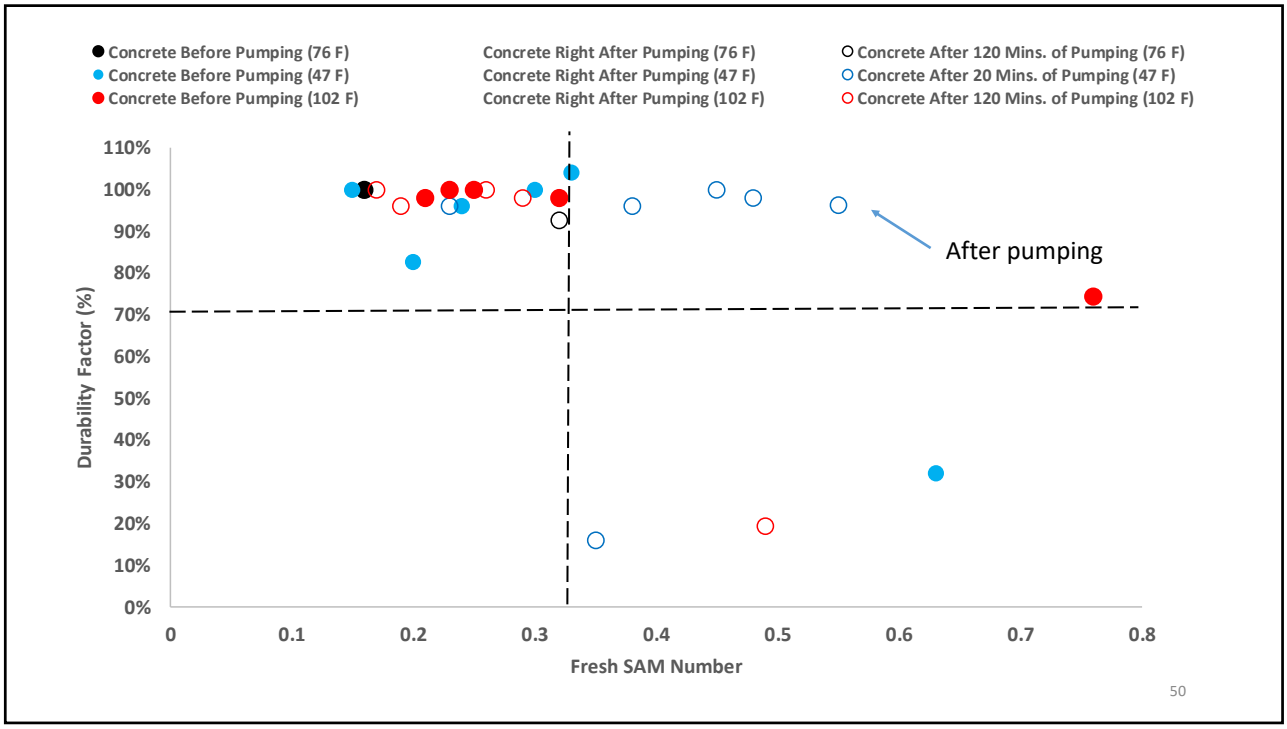
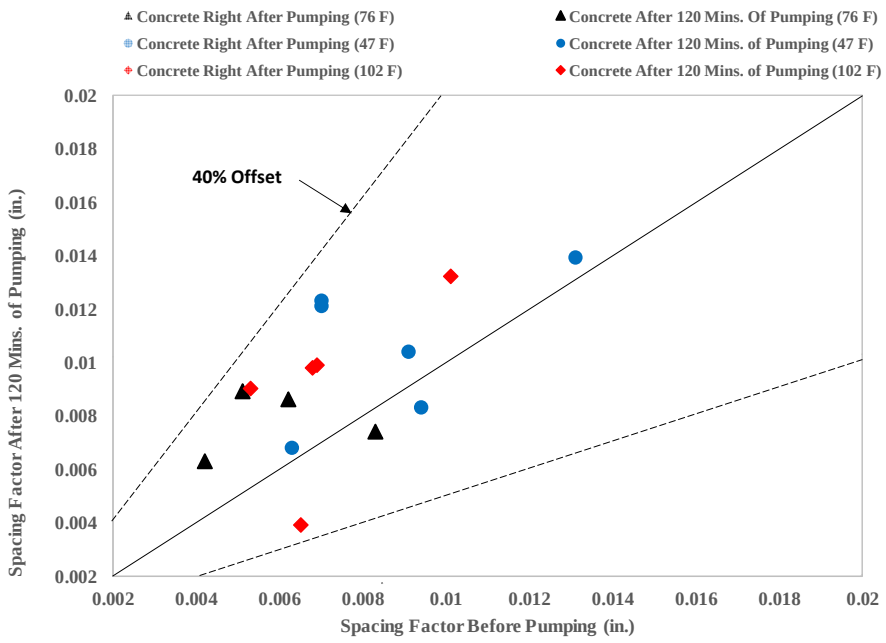
Concrete Right After Pumping (76 F)
Concrete Right After Pumping (47 F)
Concrete Right After Pumping (102 F)
Concrete After 120 Mins. of Pumping (76 F)
Concrete After 20 Mins. of Pumping (47 F)
Concrete After 120 Mins. of Pumping (102 F)
Durability Factor (%)
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Fresh SAM Number
49


Concrete Before Pumping (76 F)
Concrete Before Pumping (47 F)
Concrete Before Pumping (102 F)
Concrete Right After Pumping (76 F)
Concrete Right After Pumping (47 F)
Concrete Right After Pumping (102 F)
Concrete After 120 Mins. of Pumping (76 F)
Concrete After 20 Mins. of Pumping (47 F)
Concrete After 120 Mins. of Pumping (102 F)
After pumping
Durability Factor (%)
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Fresh SAM Number
50



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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 <u>on the hardened concrete</u> taken before and after pumping.

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

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Does this hold for other equipment and mixtures?

What is going on in the field?

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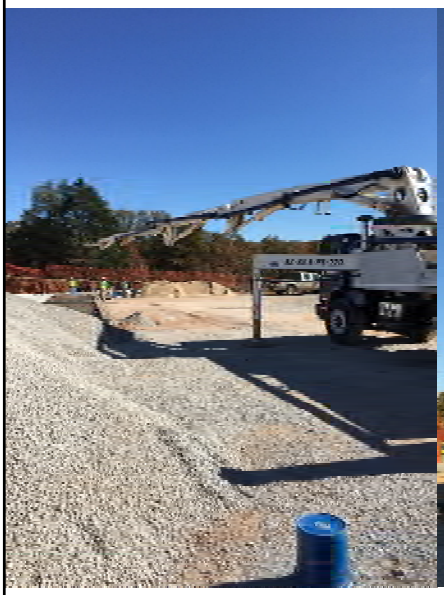
Field Pumping Information

- 30 different projects
- 62 different mixtures tested
- 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

Flat | Arch | A-Frame



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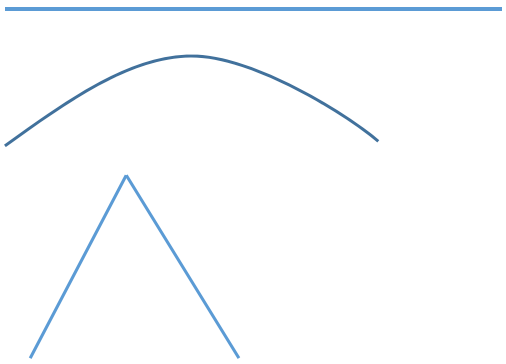
Pump configurations

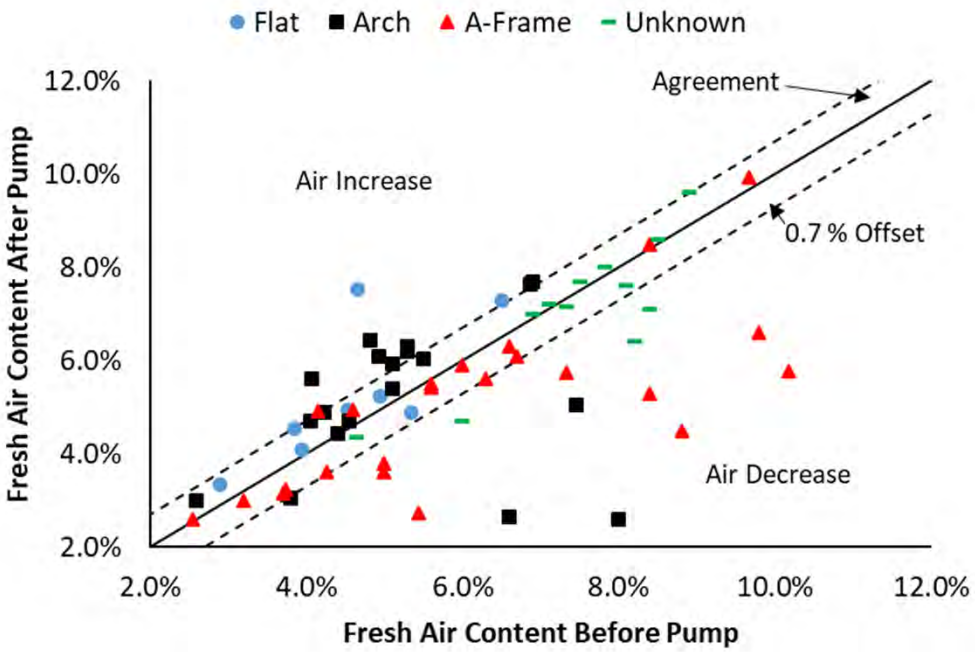


Flat

Arch

A-frame

56



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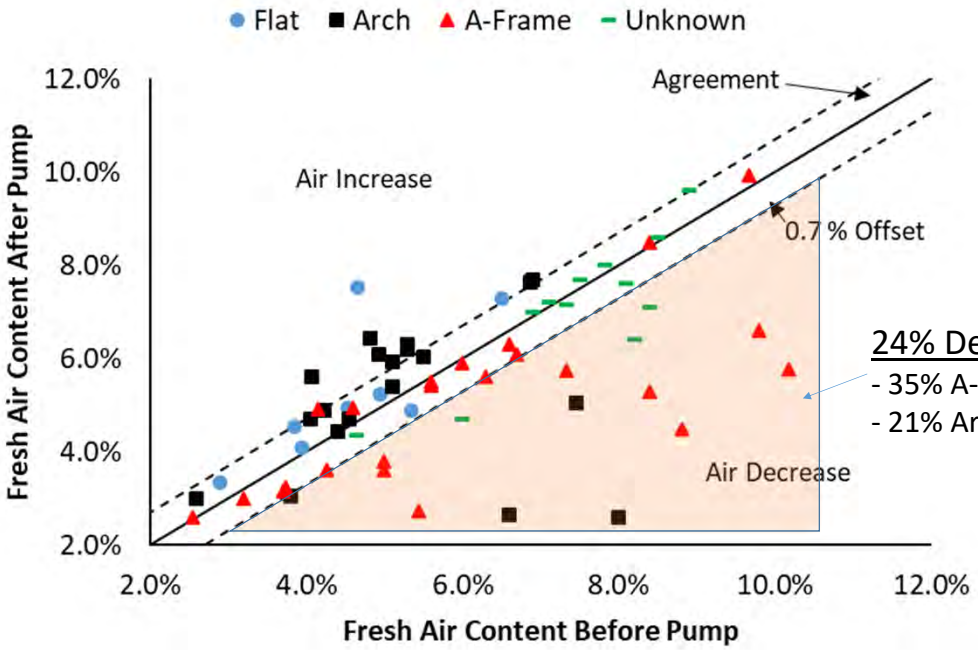
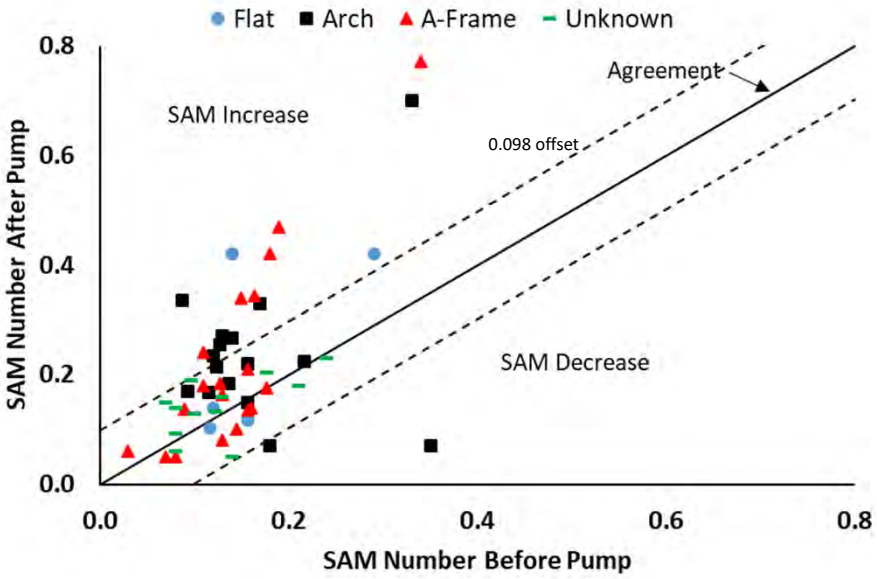


24% Decrease
- 35% A-Frame
- 21% Arch

58



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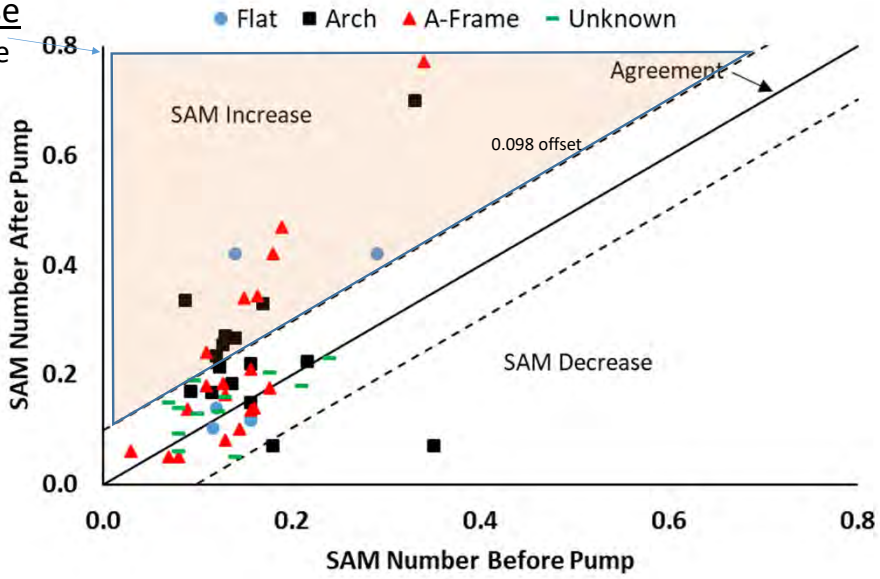
29% Increase
- 32% A-Frame
- 44% Arch
- 40% Flat



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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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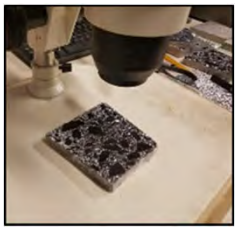
How about the hardened concrete?



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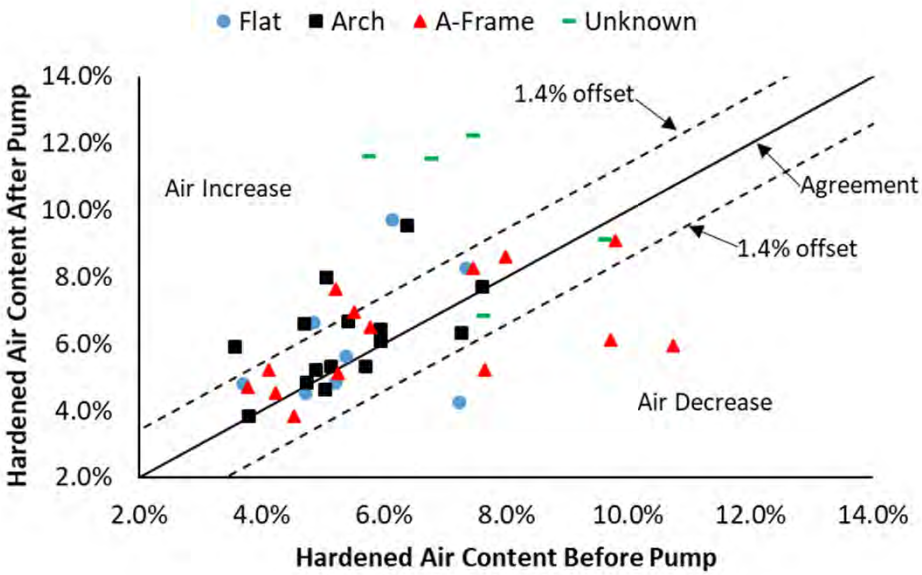
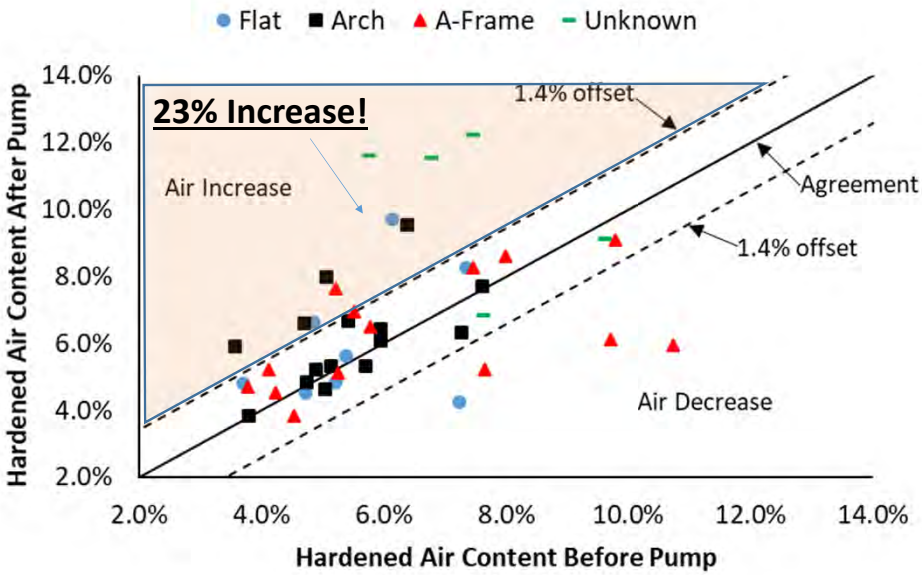
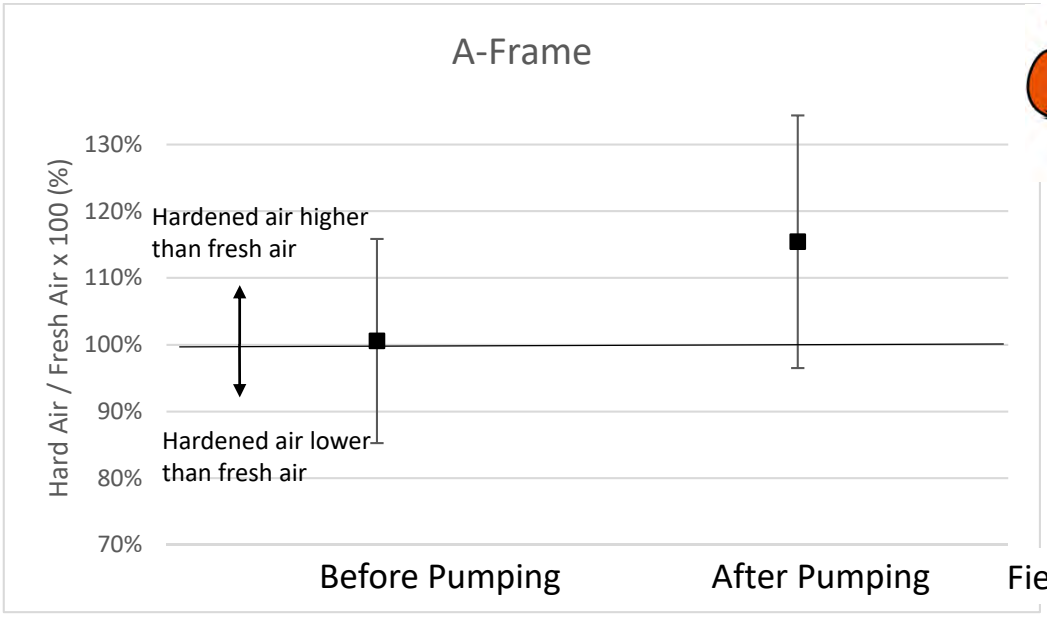

Flat
Arch
A-Frame
Unknown
Hardened Air Content After Pump
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
1.4% offset
Air Increase
Agreement
1.4% offset
Air Decrease
2.0%
4.0%
6.0%
8.0%
10.0%
12.0%
14.0%
Hardened Air Content Before Pump

63

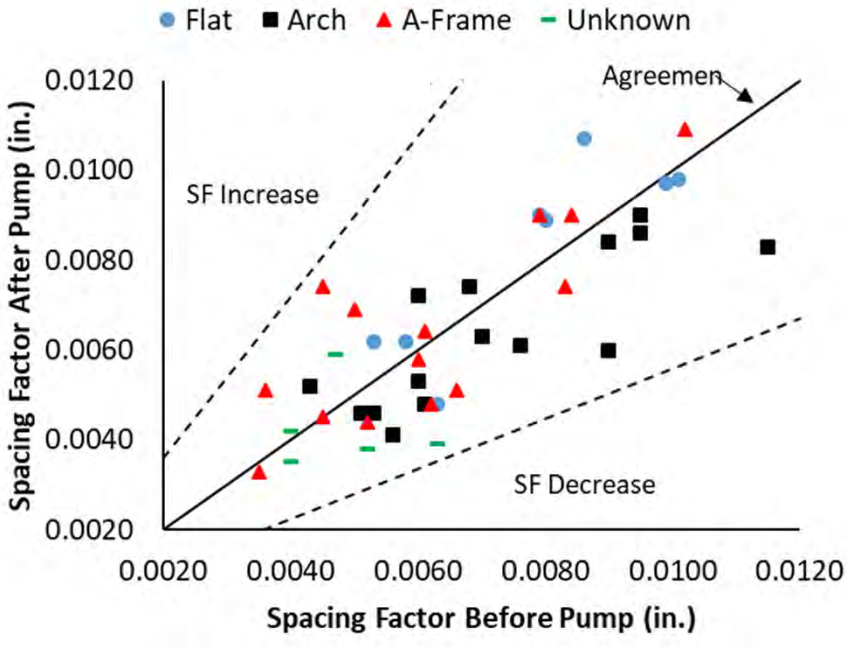

Flat
Arch
A-Frame
Unknown
Hardened Air Content After Pump
14.0%
12.0%
10.0%
8.0%
6.0%
4.0%
2.0%
23% Increase!
1.4% offset
Air Increase
Agreement
1.4% offset
Air Decrease
2.0%
4.0%
6.0%
8.0%
10.0%
12.0%
14.0%
Hardened Air Content Before Pump

64



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

65



66

Discussion

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

67

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?

69

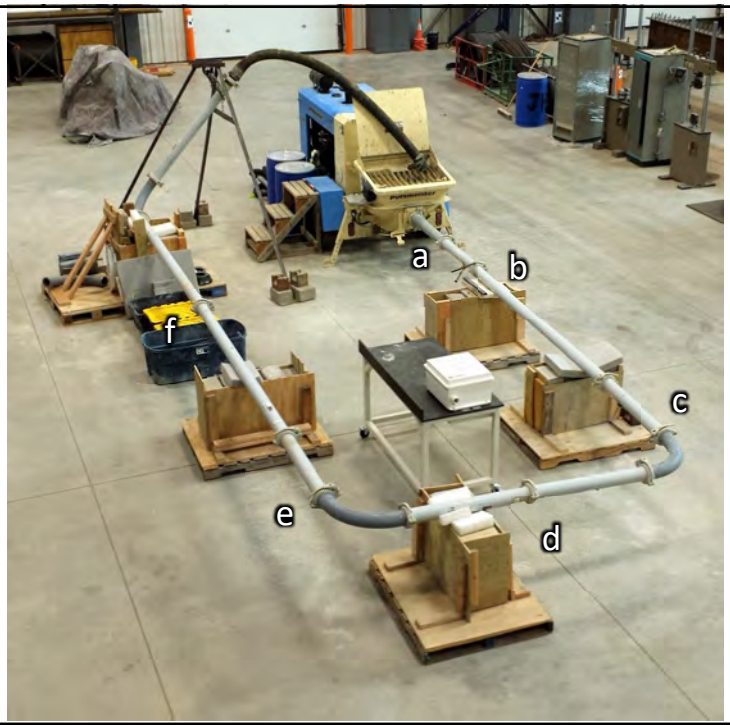
What is happening?

Back to the lab!!!!

70

Where does the air change within the pump network?

71



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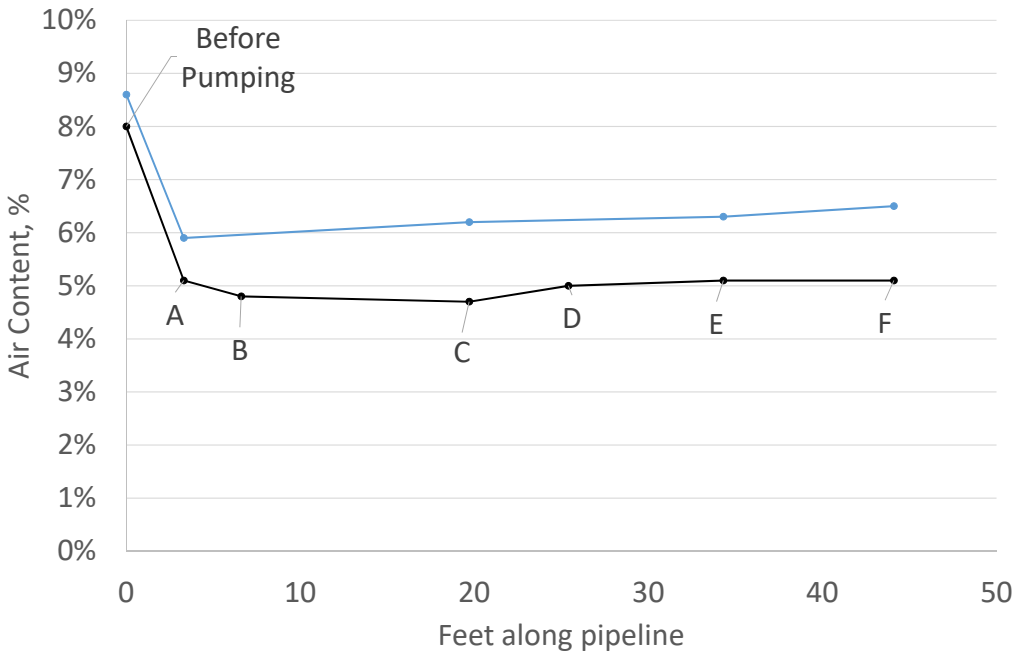

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Discussion

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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What does this mean?

The high pressures from the pump are causing the air to dissolve.

This happens in lab and field concrete with temperature ranges from 35°F to 111°F.

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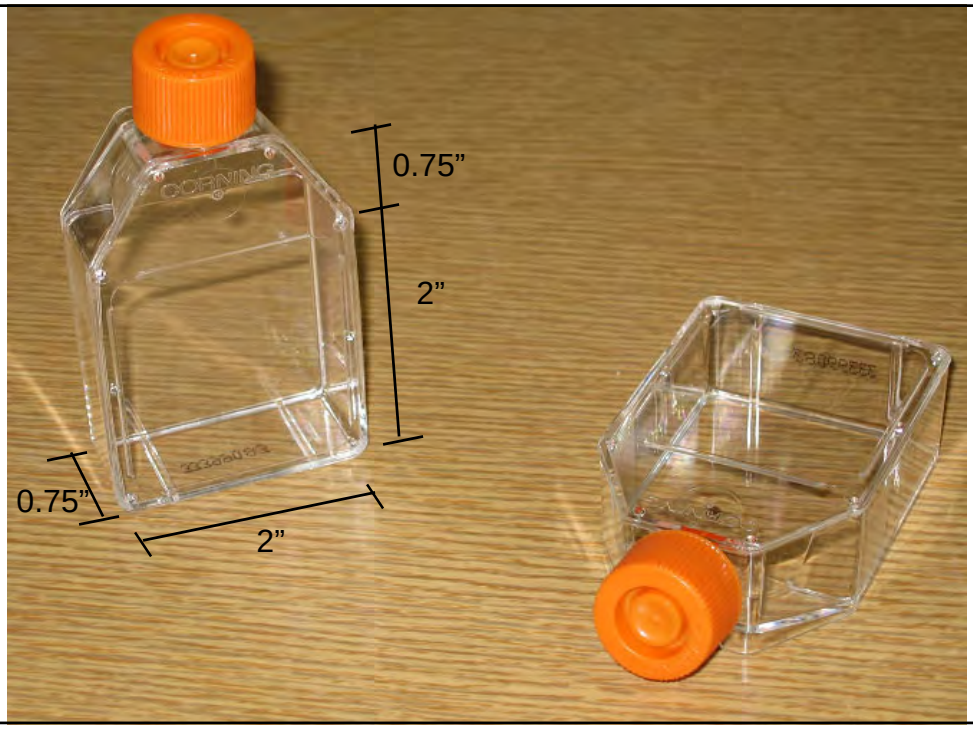
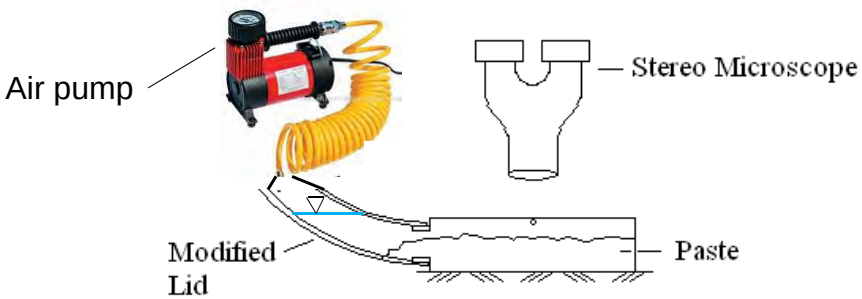
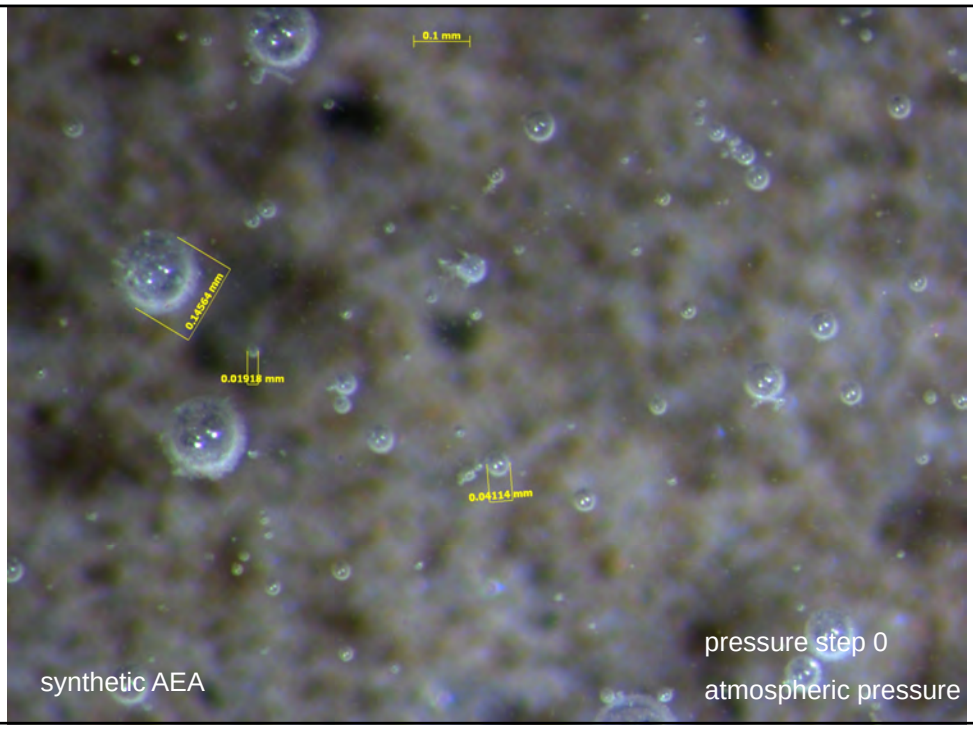
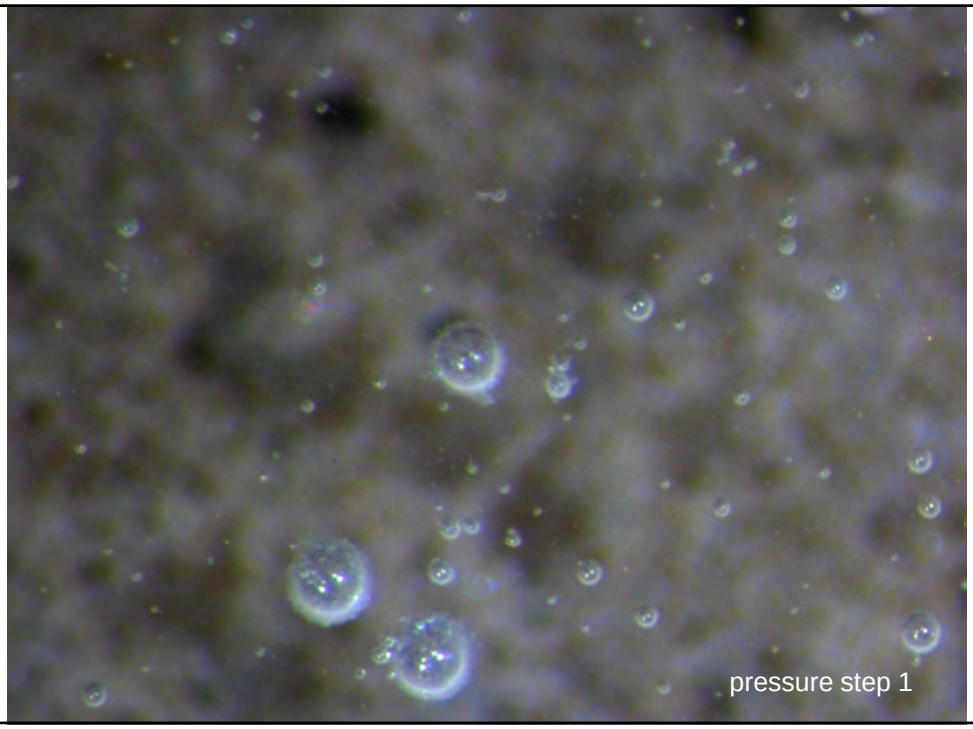
How does the pressure change the bubble size distribution?

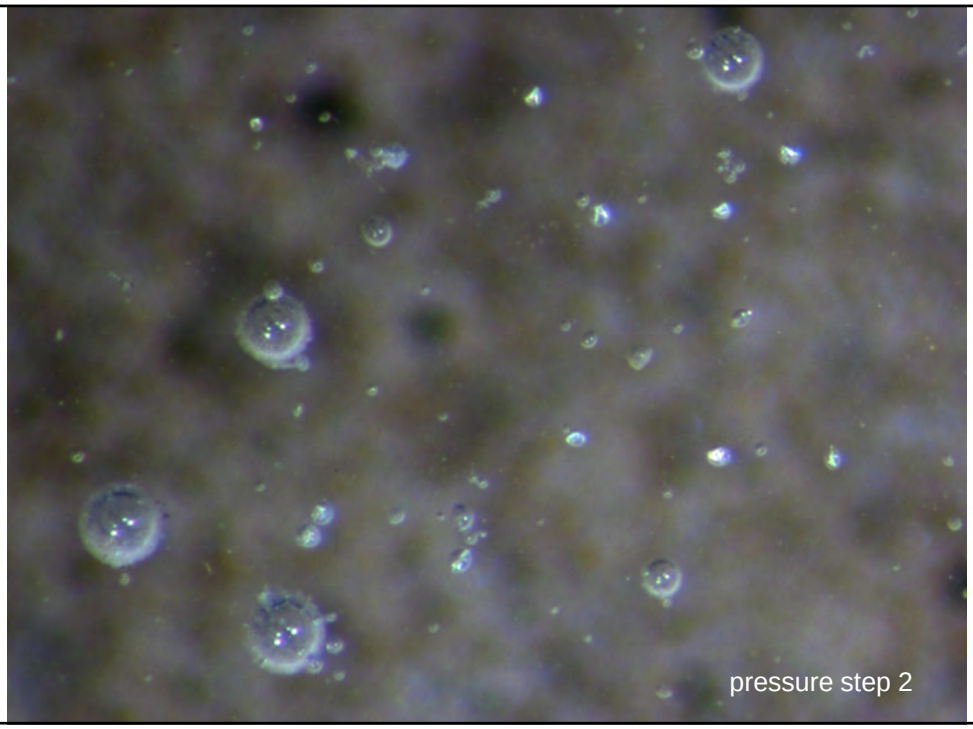
77

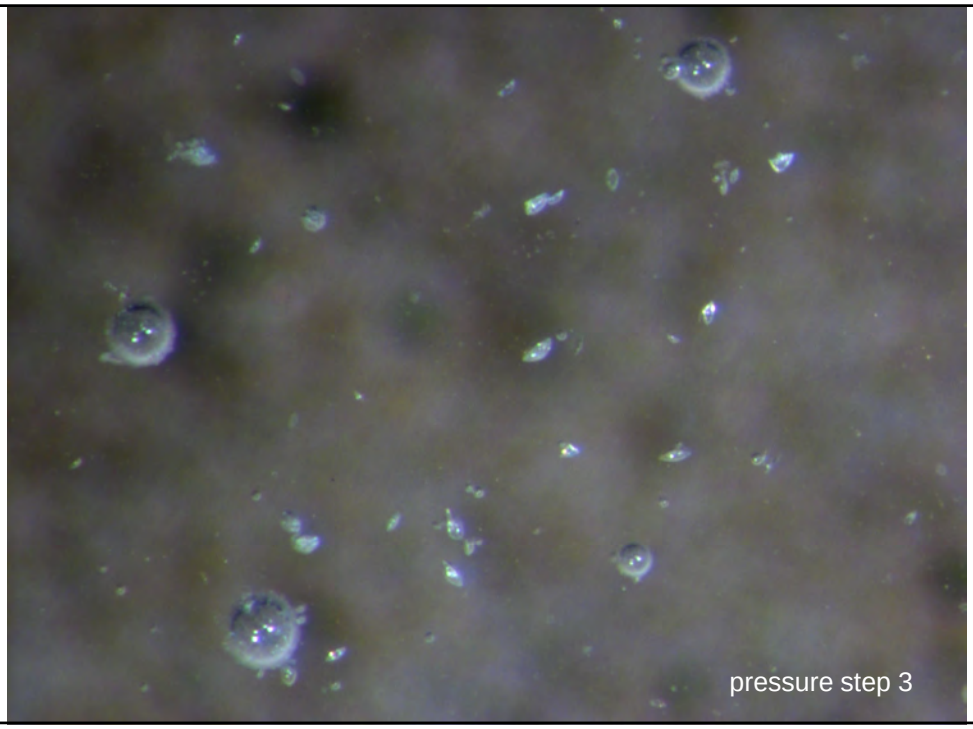


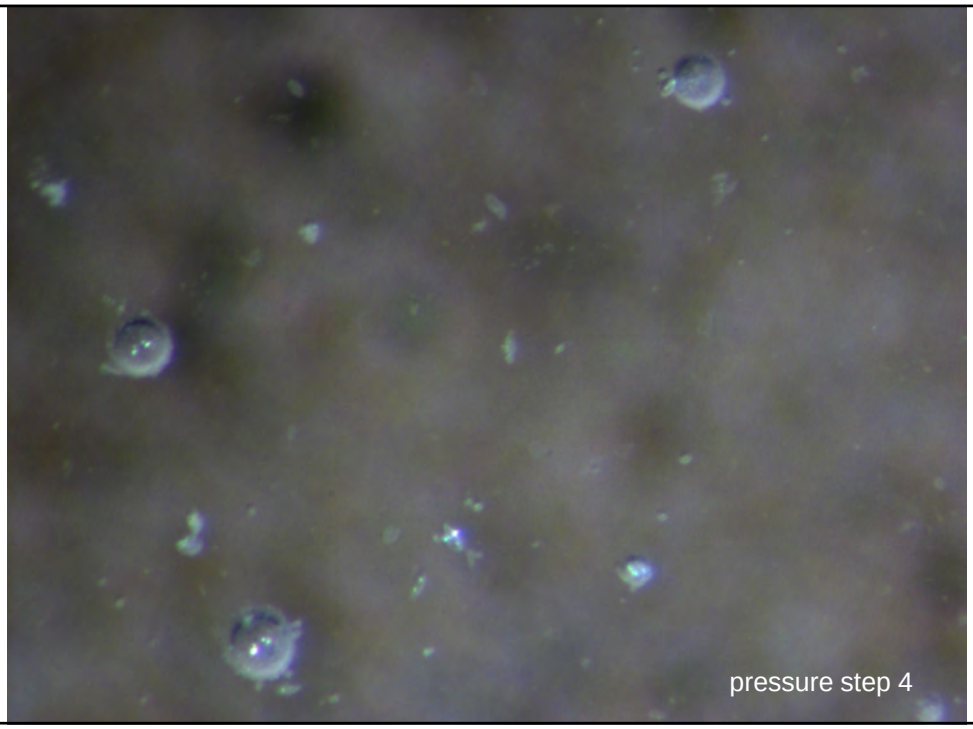

Air pump
Stereo Microscope
Modified Lid
Paste

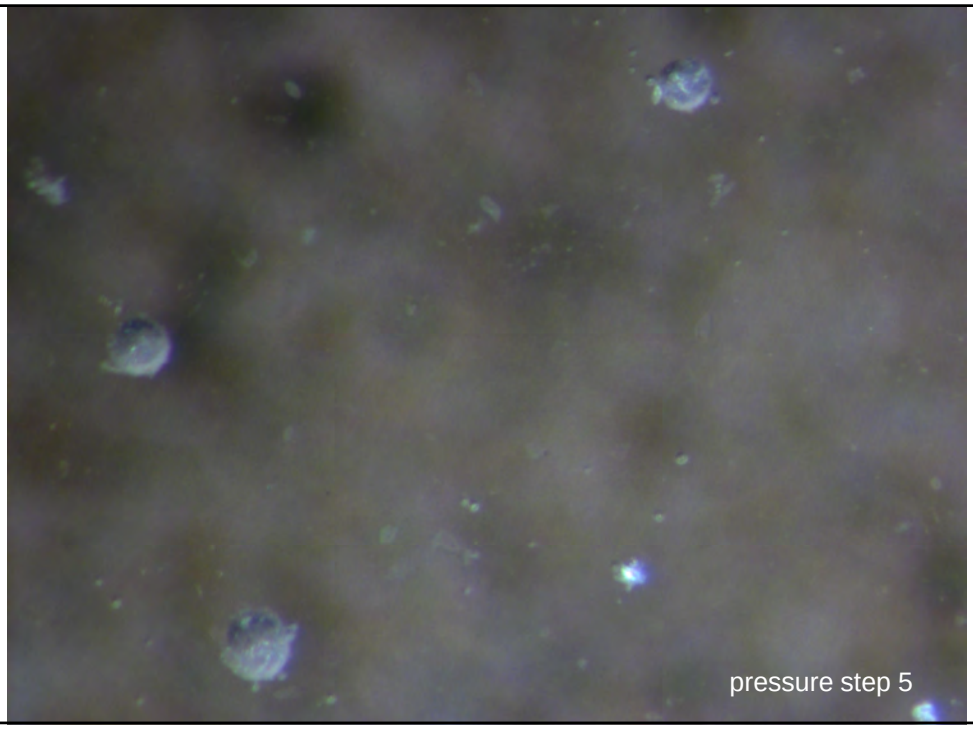

0.1 mm
0.14564 mm
0.01918 mm
0.04114 mm
synthetic AEA
pressure step 0
atmospheric pressure

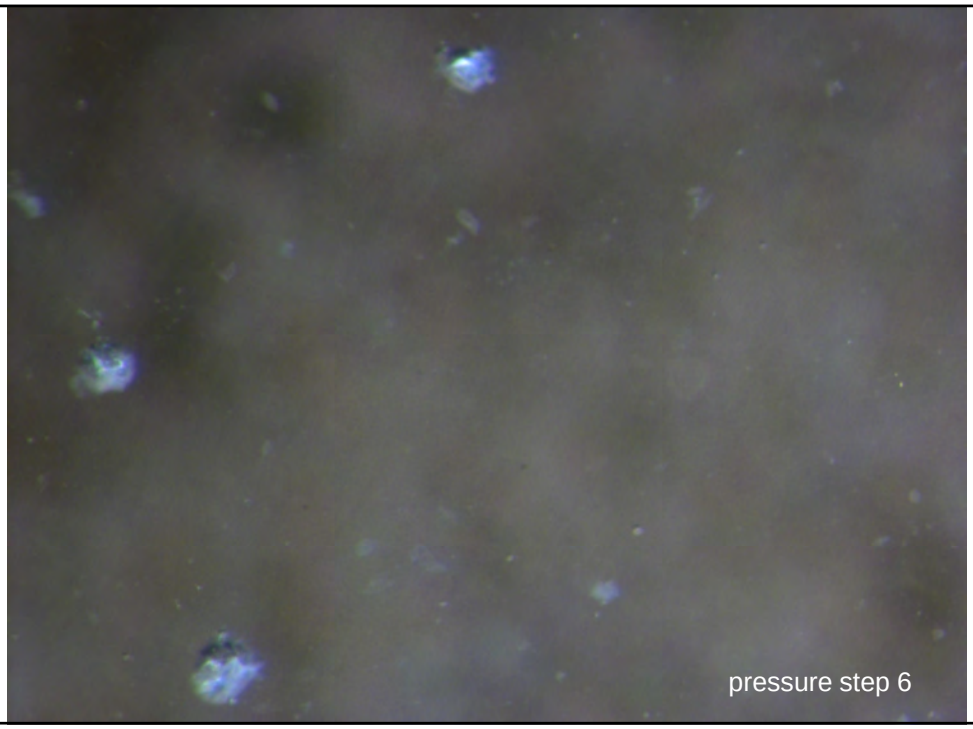

pressure step 1

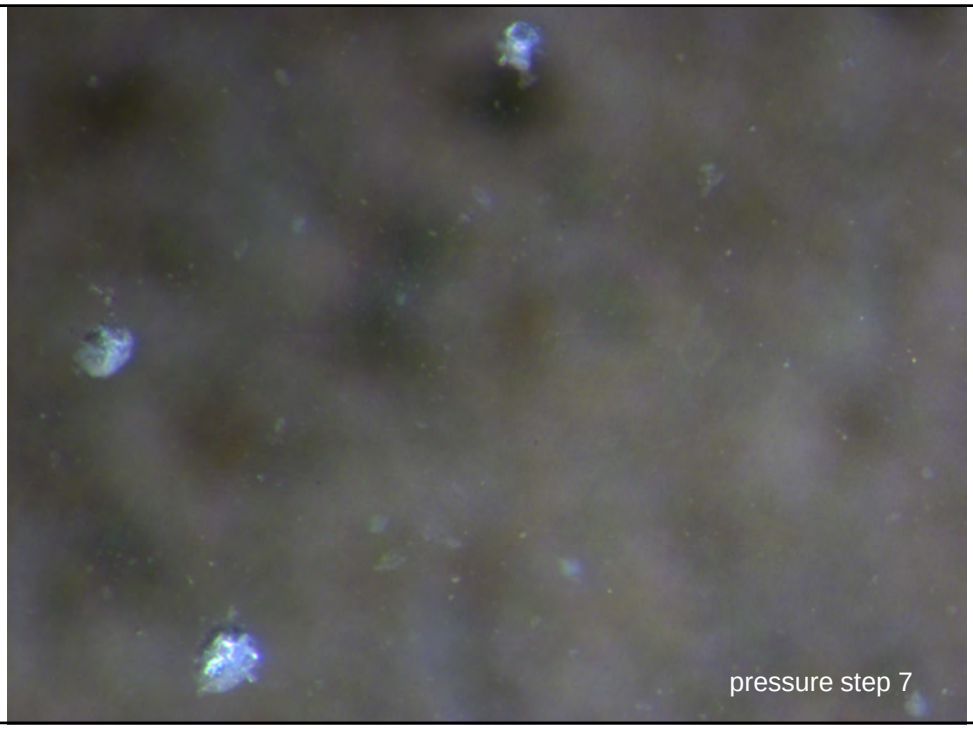

pressure step 2

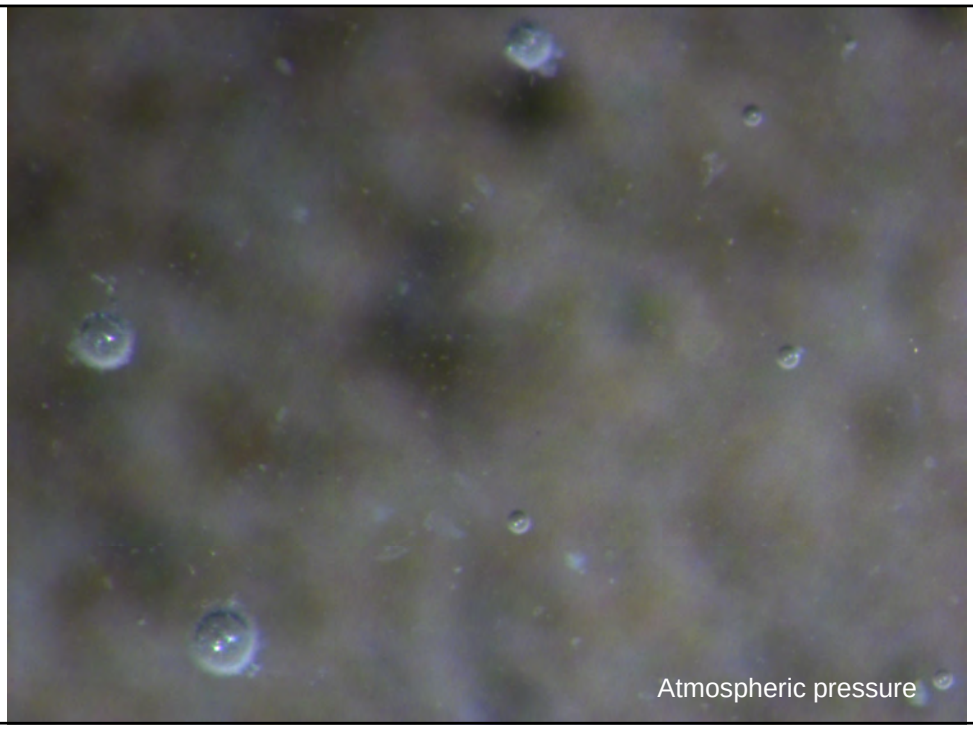

pressure step 3

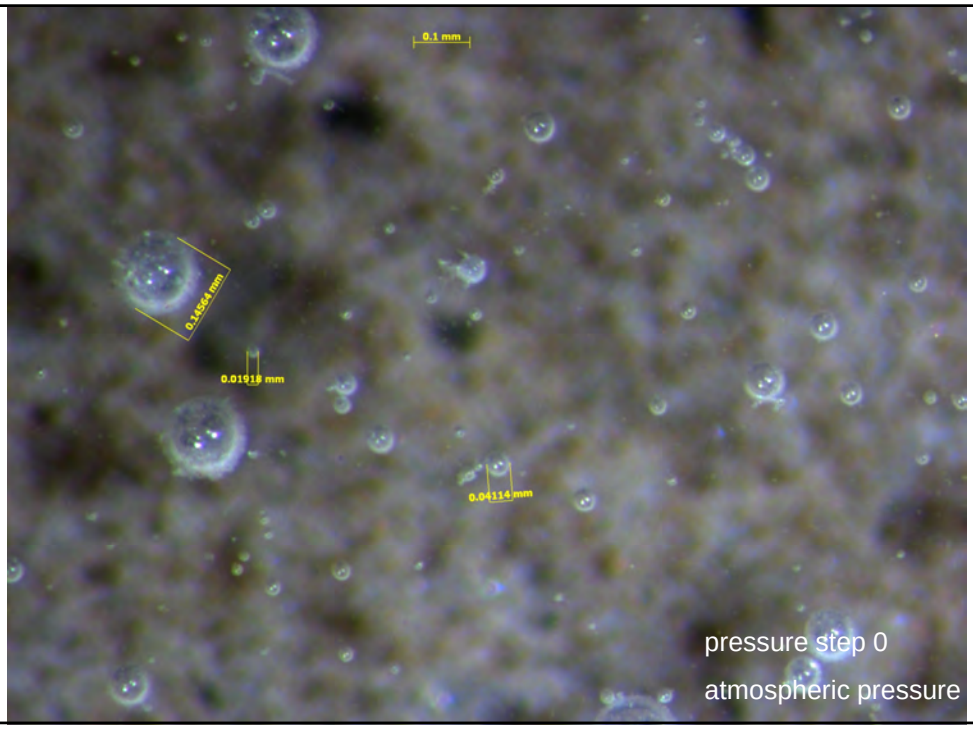

pressure step 4


pressure step 5


pressure step 6


pressure step 7


Atmospheric pressure


0.1 mm
0.14564 mm
0.01918 mm
0.04114 mm
pressure step 0
atmospheric pressure

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.

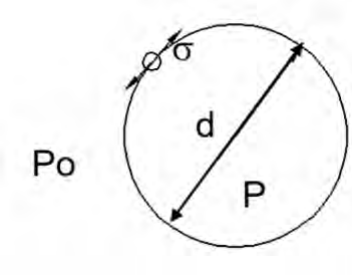
91

Why do the small bubbles dissolve???

Laplace-Young Equation

$P_1=P_0+4\sigma/d$

P_1=internal pressure of the air bubble
P_0=pressure of fluid surrounding the bubble
σ=surface tension of the bubble film
d=bubble radius

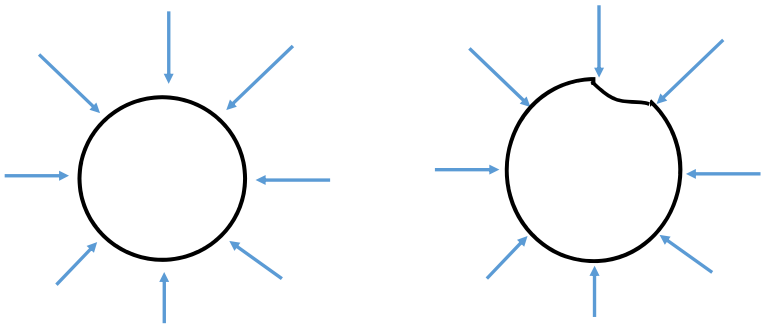


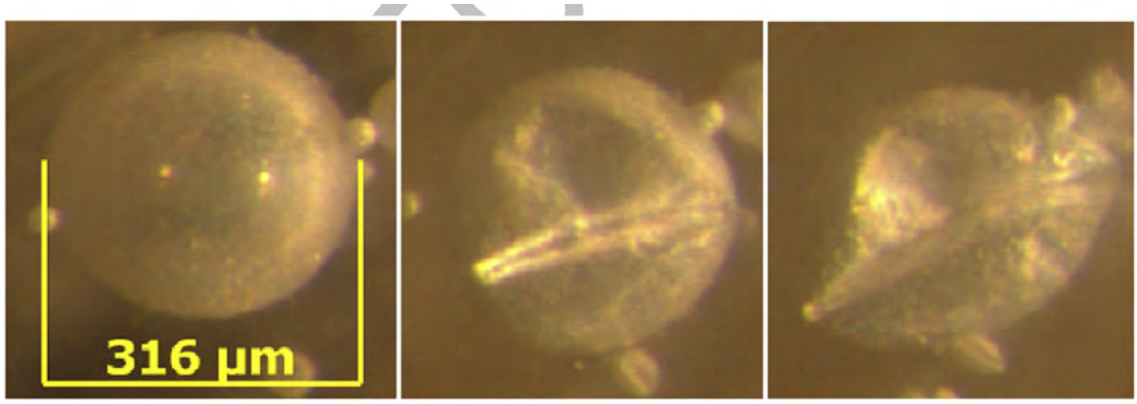
This means the small bubbles have higher pressure than the large bubbles.

92

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.





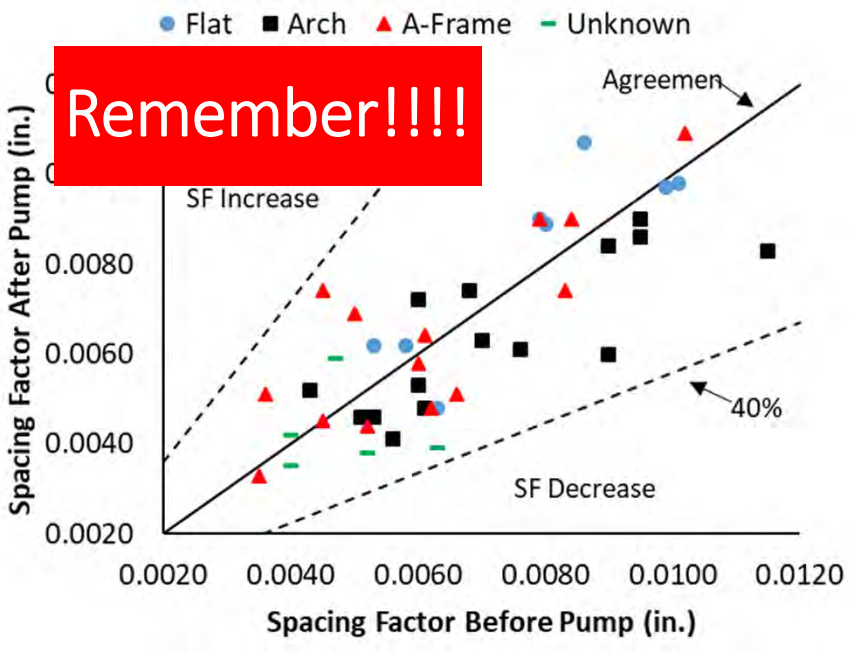
a – 0 bar b – 0.3 bar c – 0.7 bar

94

What does this mean?

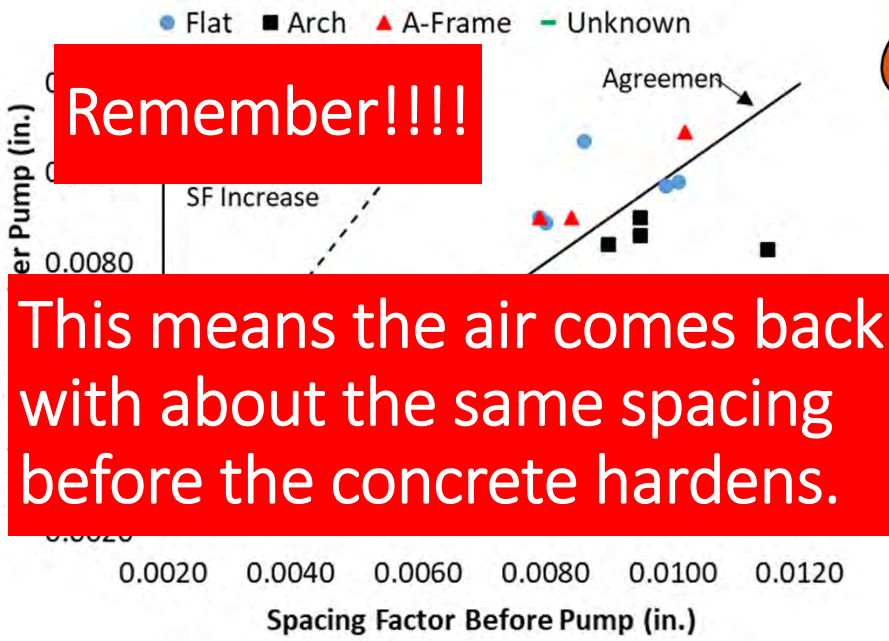
- The high pressures during pumping cause the small bubbles to become damaged and dissolve.
- Since the small bubbles are dissolved this means that they are not present in the fresh concrete as it leaves the pump.
- This is why the air volume decreases and the SAM Number increases.

95



Remember!!!!

96



Remember!!!!

This means the air comes back with about the same spacing before the concrete hardens.

97

98

How does air change over time AFTER pumping?

99

Sample concrete before and after pumping

Sampling time after pumping

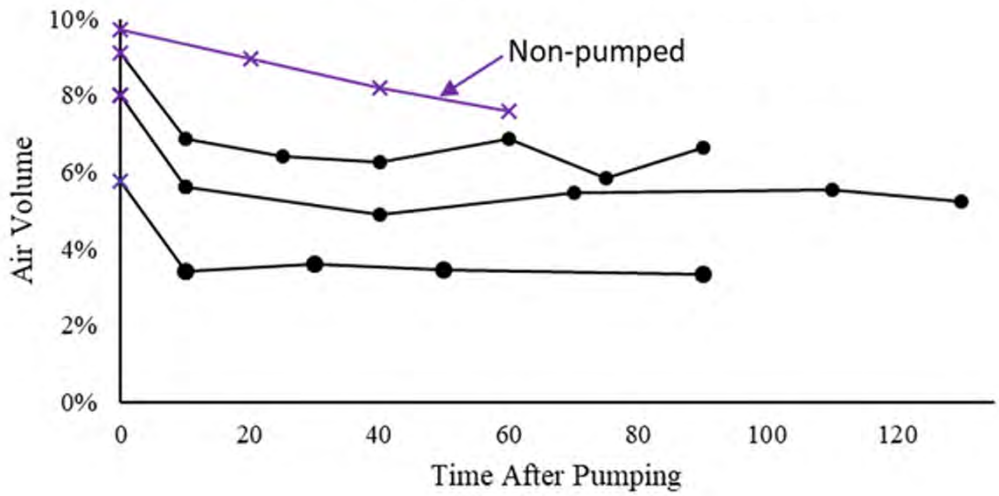
0 min

15 min

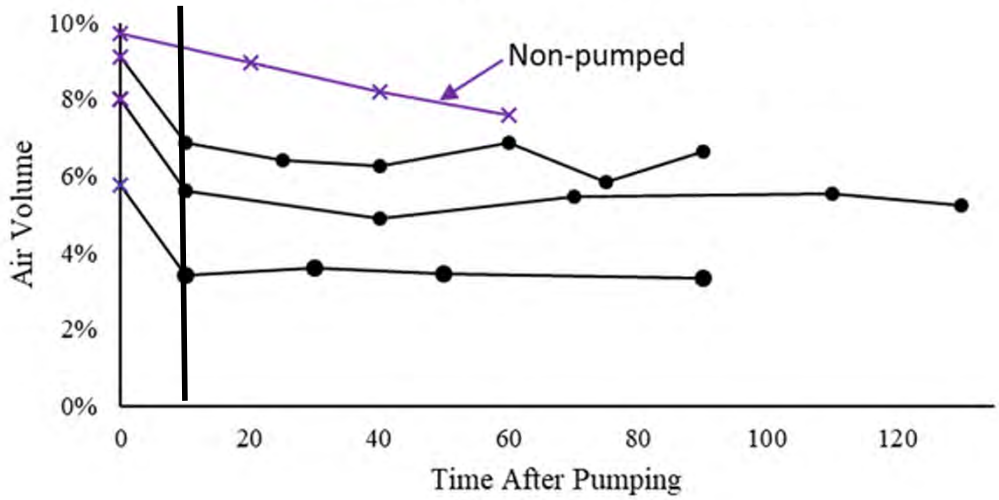
30 min

45 min

100


10%
8%
6%
4%
2%
0%
Air Volume
Non-pumped
0
20
40
60
80
100
120
Time After Pumping

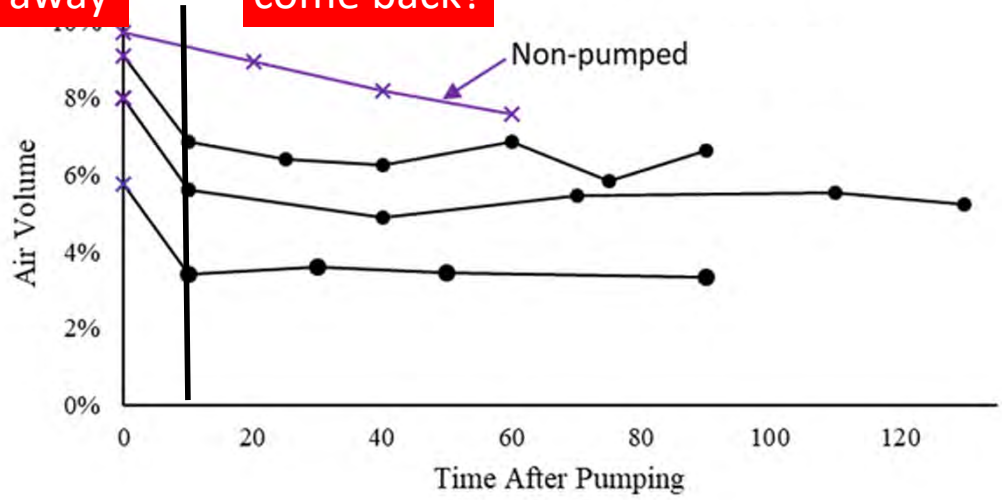
101


10%
8%
6%
4%
2%
0%
Air Volume
Non-pumped
0
20
40
60
80
100
120
Time After Pumping

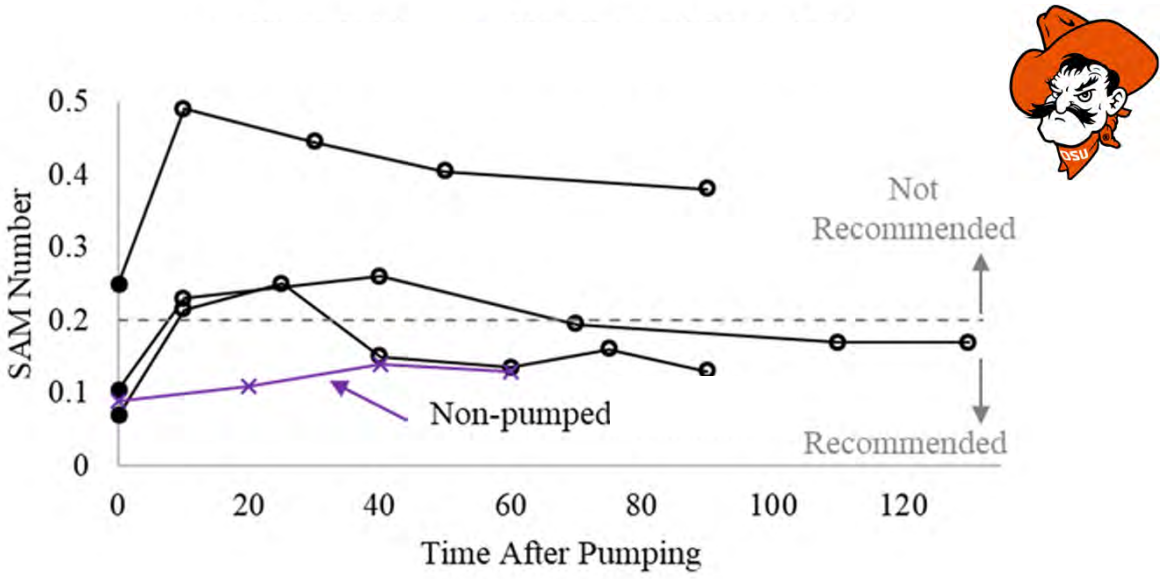
102

Bubbles go away

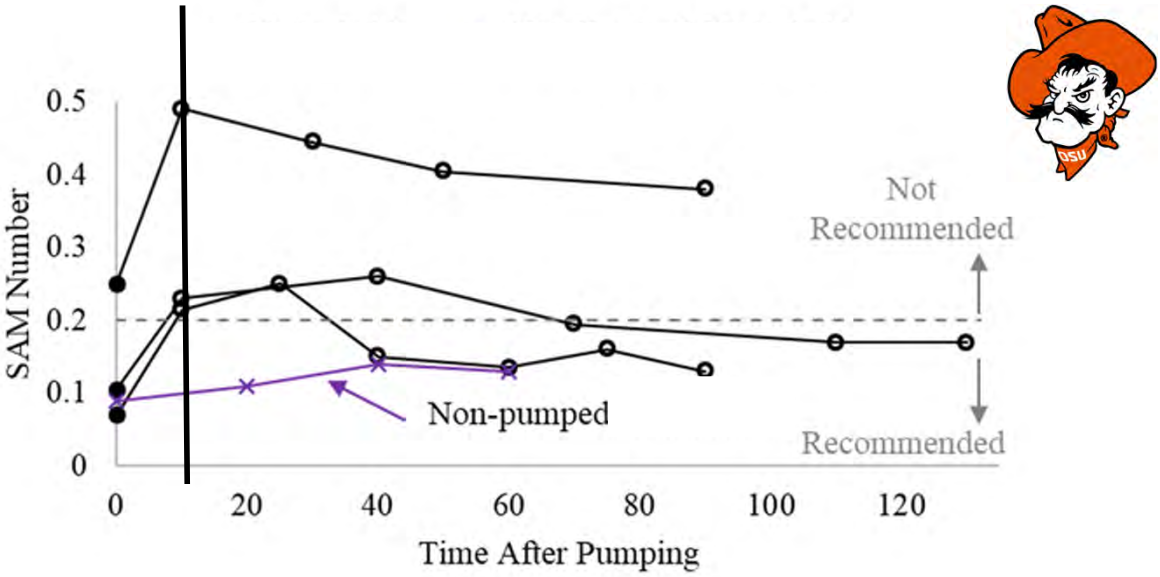
Bubbles come back?



103



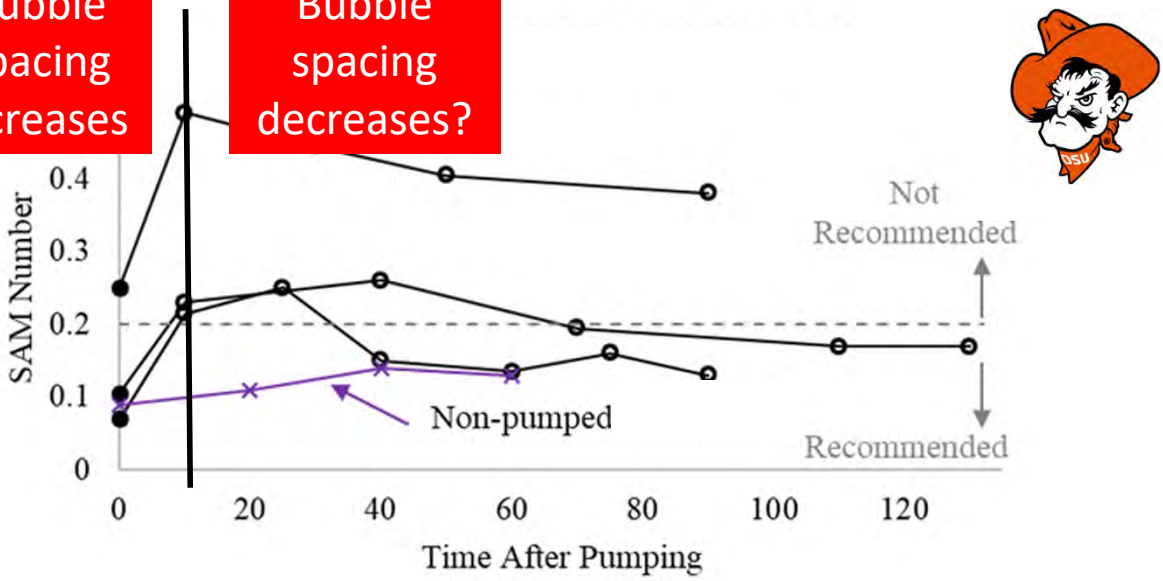
104



105

Bubble spacing increases

Bubble spacing decreases?



106

How does temperature impact this?

Hotter mixes air comes back faster.

Colder mixer air comes back slower.

Theh temperature is not a big deal because the bubbles always come back!

107

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.

108

109

110


STAR WARS
RETURN OF THE JEDI

111


STAR WARS
RETURN OF THE JEDI
BUBBLES

112

What does this mean?

- **Because of the high pressures during pumping the air content and SAM after pumping 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.

113

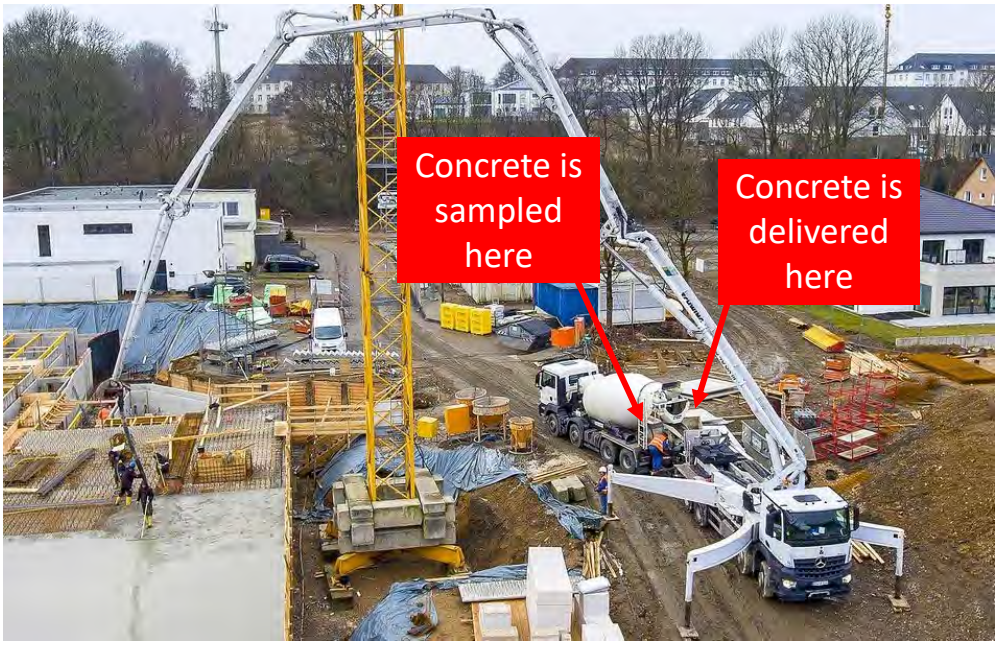
What do I think needs to happen?

- 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.

114

115

116



117

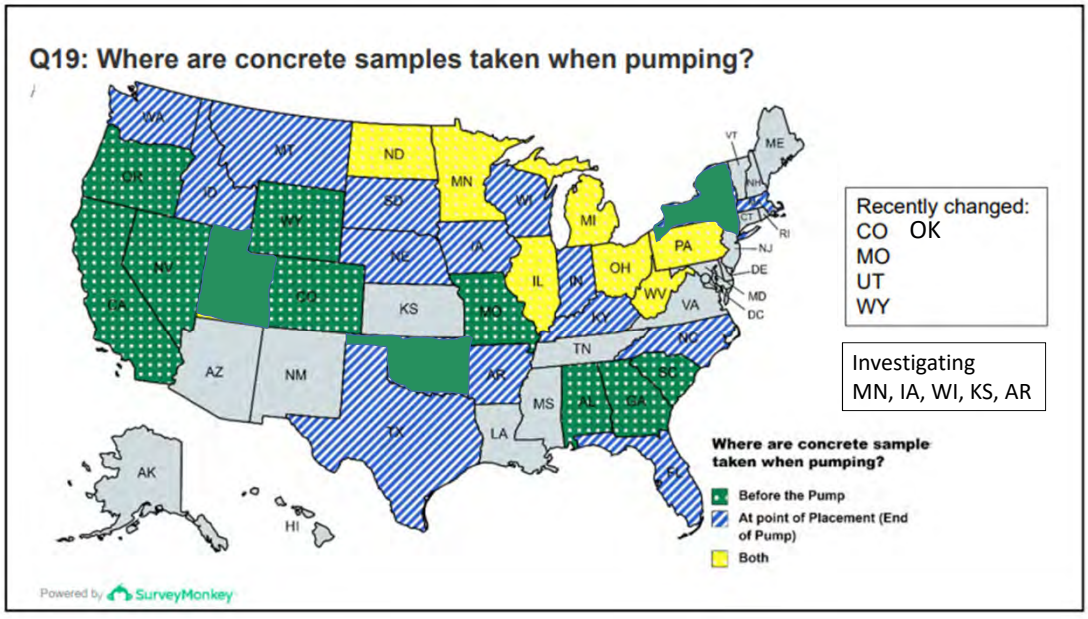
What do I think needs to happen?

- I think mixtures should be tested with the SAM during mixture design approval and regularly verified in the field.
- Pumping specifications need to change to only require sampling before the pump.

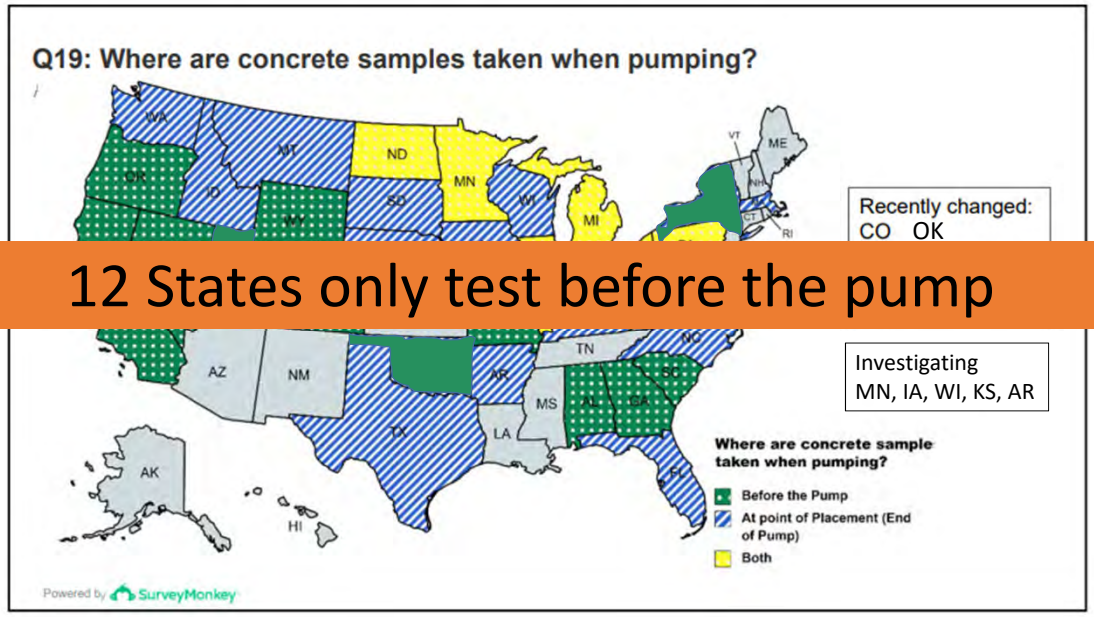
118

What are other states doing?

119



120



121

What do you think?

122

1. Do you feel like we need to change the sampling location during pumping?

2. Why do you feel this way?

123

1. Do you feel like we need to change the sampling location during pumping?

2. Why do you feel this way?

3. What do you need to make this change?

4. What can you do today to take action?

124

How much data is enough?

How much data is enough?

- 62 Field tests
  - 30 projects
  - 18 different pumps
  - 3 boom configurations
- 48 concrete Lab tests
  - Room temp
  - Hot
  - Cold
  - Where do we lose air and how does it come back?

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.

127

www.youtube.com/tylerley


Questions?
www.tylerley.com/pumping
www.superairmeter.com
Tyler.ley@okstate.edu

129

130

What can I do to avoid air loss?

Air loss seems to happen more in the following situations:

- Higher pumping pressures
- Smaller diameter lines
- Mixtures with poor aggregate gradations
- Lower slump mixtures
- A-frame and arch configurations

131

Sam Field Study

21 State DOTs + 1 Canadian Province helped analyze **231 concrete mixtures from 110 different projects**

More than: 15 different SAMs and operators, 62 different aggregates, 19 cement sources, 20 different fly ashes , 39 different admixtures

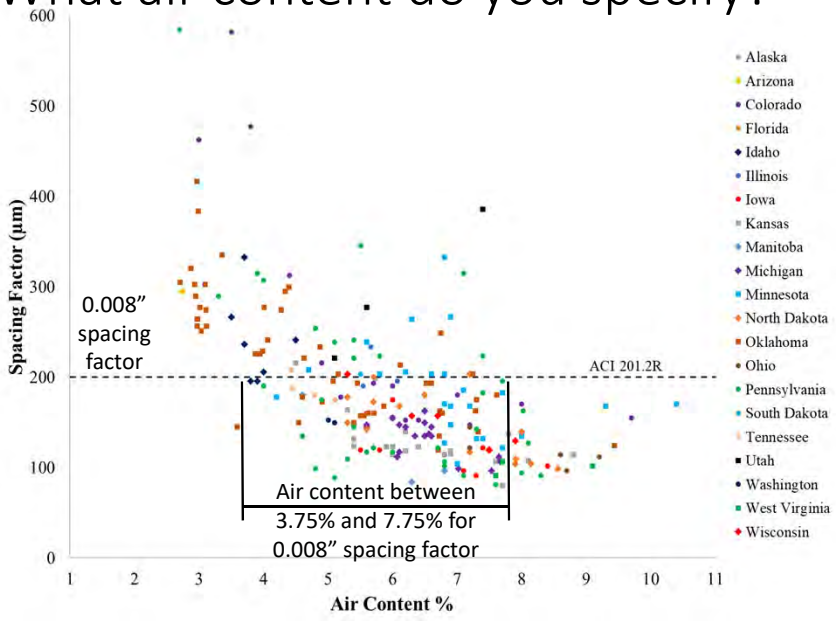
60% pavements, 20% bridge decks, and 20% other

self-consolidating, precast, ready mix, and central mix concrete

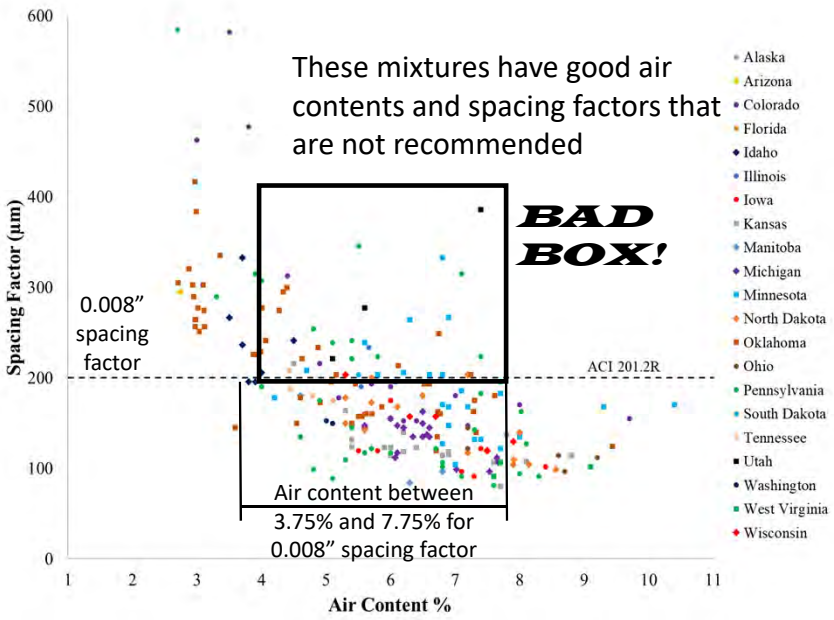
Thank you to all that helped!

What air content do you specify?

231 field mixes

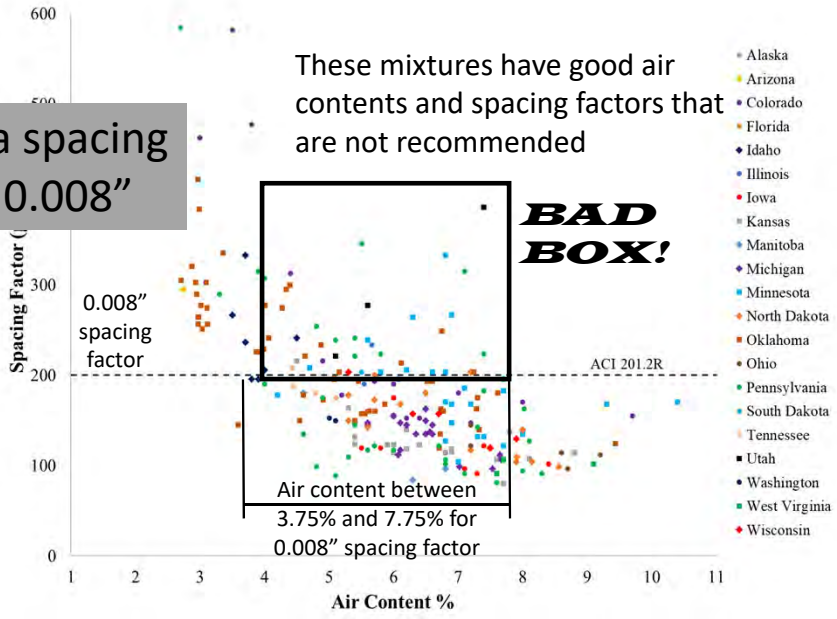


231 field mixes



231 field mixes

1/4 have a spacing factor > 0.008"



Summary

- **We need to know the size of bubbles within the concrete**
- *The volume of air does not tell you about bubble size*
- *25% of the time we are accepting concrete that does not meet the recommended air void quality*
- What if we could measure this in the fresh concrete???

Other studies with similar findings

- Iowa DOT
- Pennsylvania DOT
- Vermont DOT
- NCHRP Project lead by Peter Taylor
- Lafarge Holcim
- UNC Charlotte
- Polish Researchers

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Limits to signify a significant change

- In order to determine if the air volume and spacing factor significantly changed the following standard deviations and coefficient of variations were used.

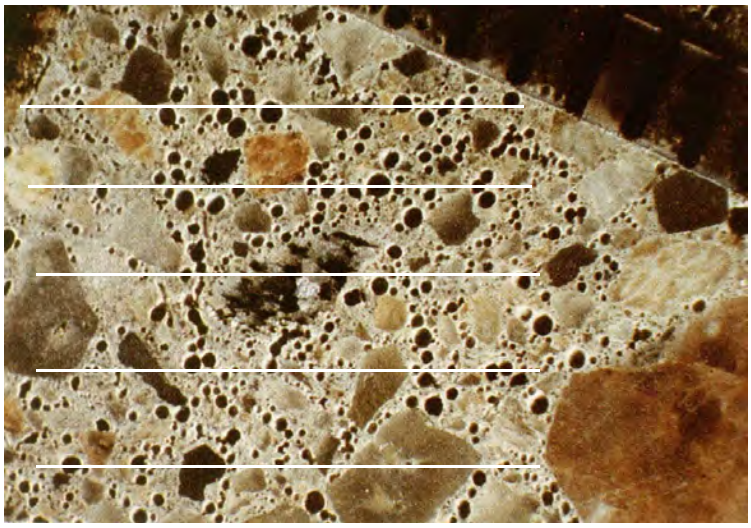
Concrete Parameter	95% Confidence Boundary (2SD's)	Referenced Standard
Fresh Air Content (%)	0.7	ASTM C231
SAM Number	0.098	AASHTO TP 118
Hardened Air Content (%)	1.42	ASTM C457
Spacing Factor (%)	40.2*	ASTM C457

-

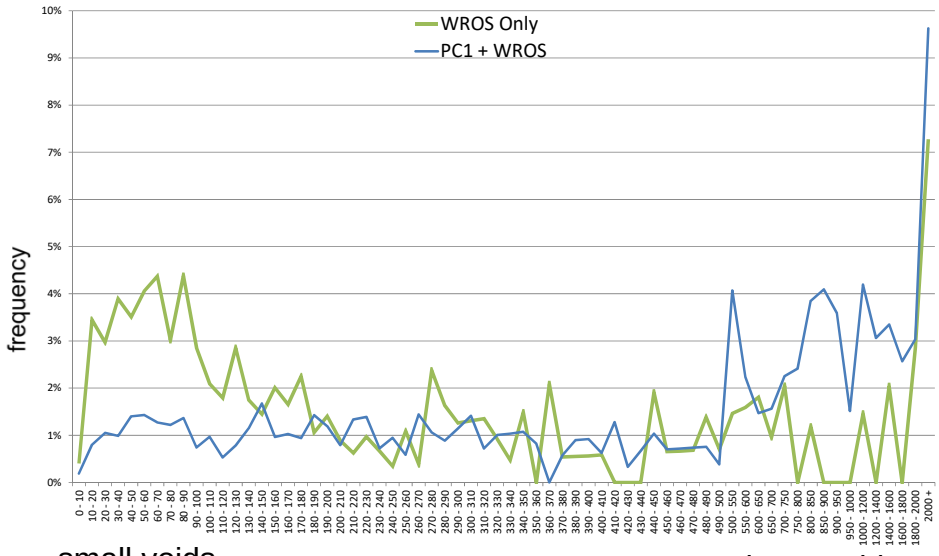
Hardened Air Void Analysis

From Hover

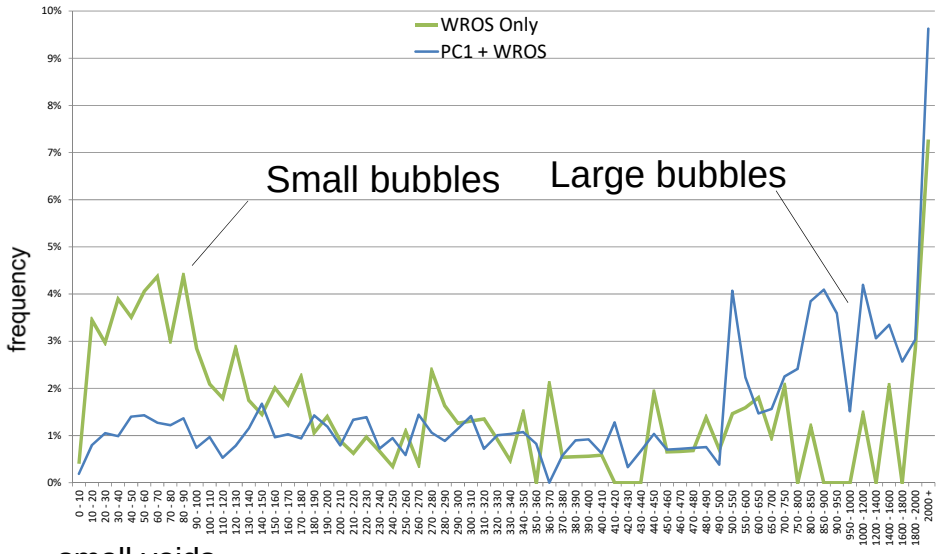
Hardened Air Void Analysis



From Hover

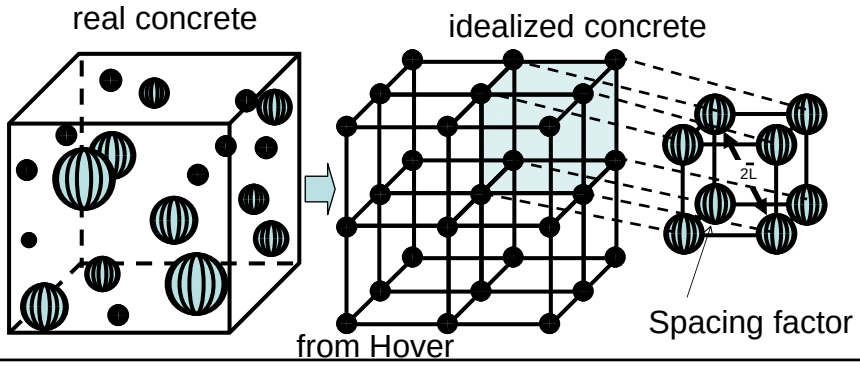


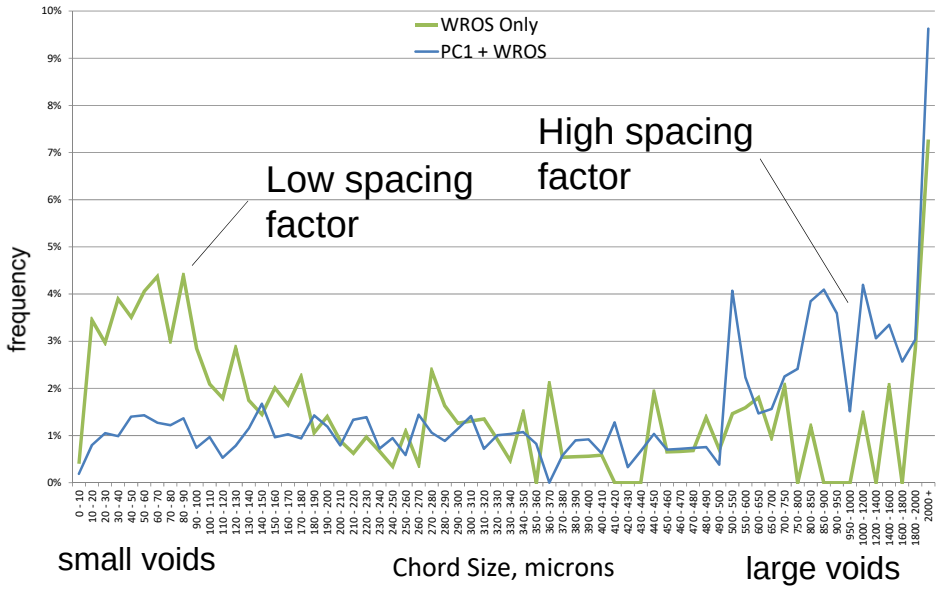
Freeman et al., 2012



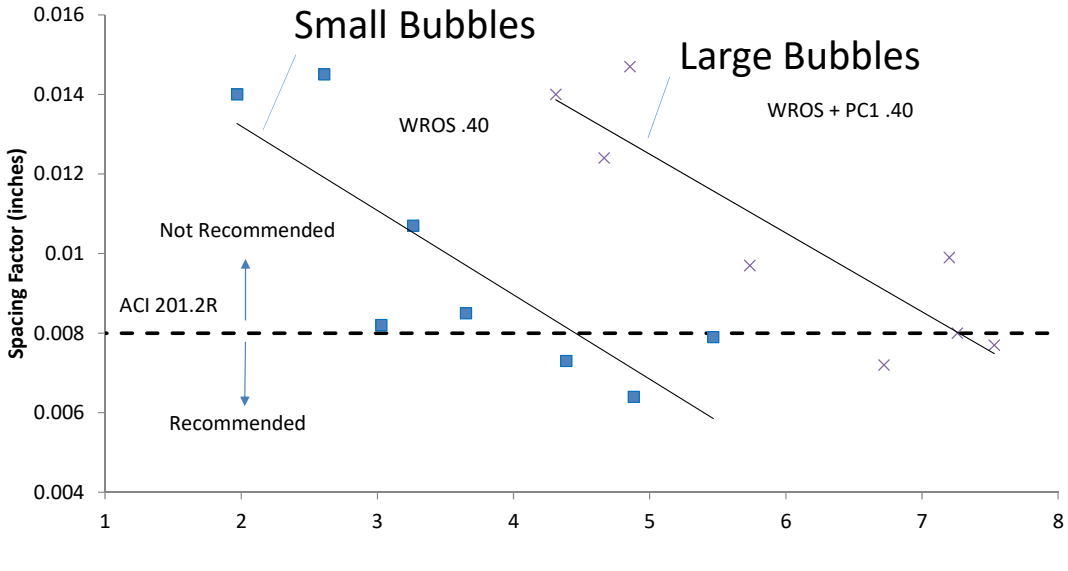
Freeman et al., 2012

- Spacing Factor – ½ of the average distance of an average sized void uniformly distributed in the paste
- **<u>Desired Value < 0.008 in (ACI 201)</u>**





Freeman et al., 2012

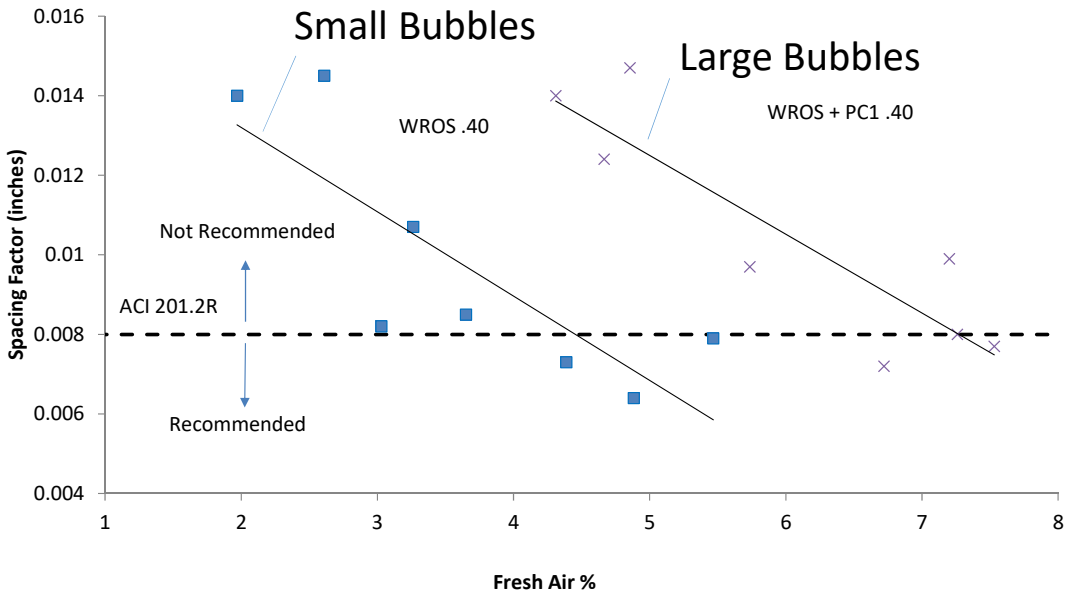


Ley et al., 2017

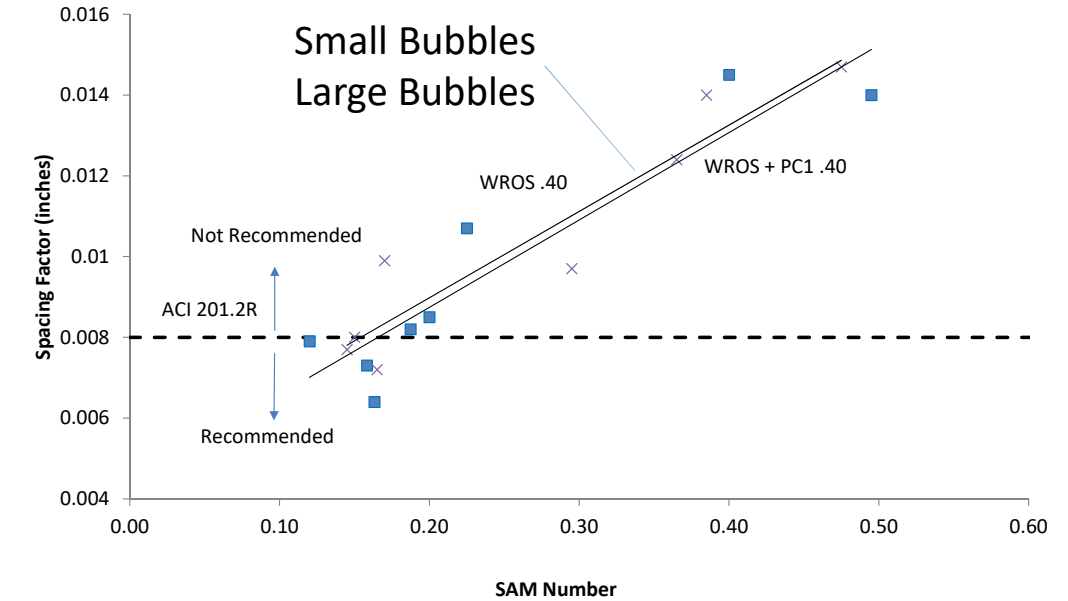
Summary

- **We need to know the size of bubbles within the concrete**
- *The volume of air does not tell you about bubble size*
- What if we could measure this in the fresh concrete???

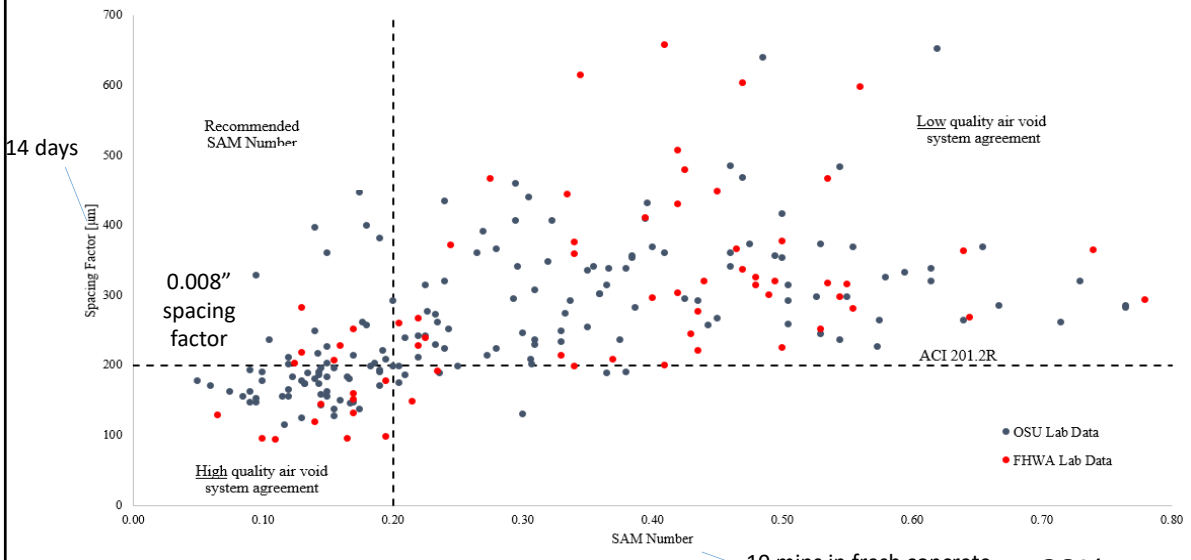
Super Air Meter (SAM)



Ley et al., 2017



Ley et al., 2017

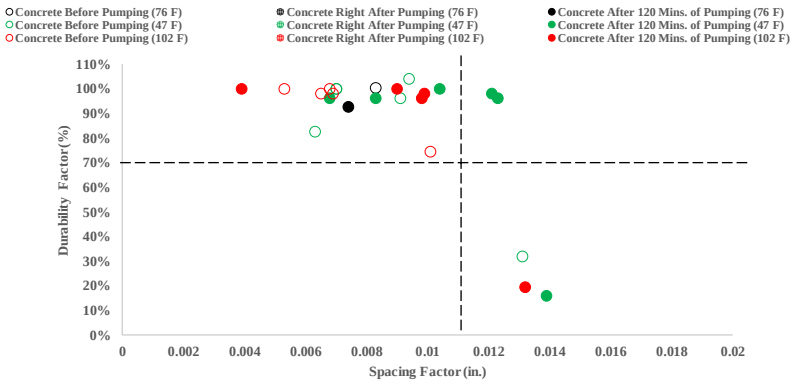


Over 227 lab mixtures from two different research groups

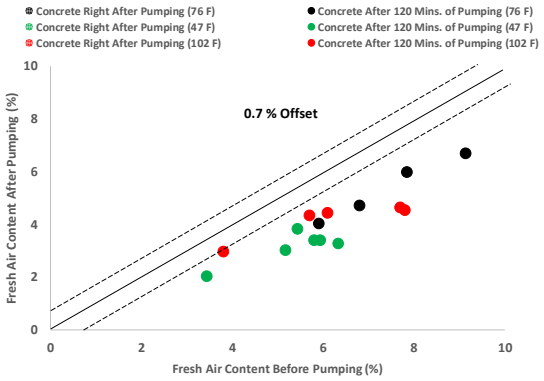
88% agreement

Ley et al., 2017

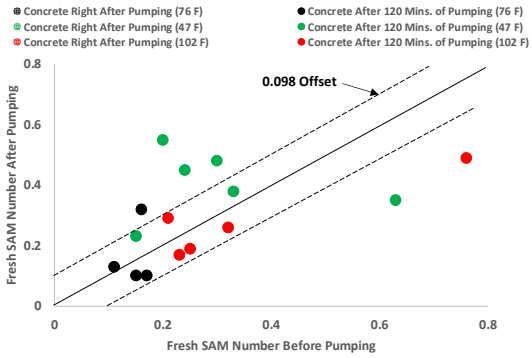
151



152


Concrete Right After Pumping (76 F)
Concrete After 120 Mins. of Pumping (76 F)
Concrete Right After Pumping (47 F)
Concrete After 120 Mins. of Pumping (47 F)
Concrete Right After Pumping (102 F)
Concrete After 120 Mins. of Pumping (102 F)
0.7 % Offset
Fresh Air Content After Pumping (%)
Fresh Air Content Before Pumping (%)
0
2
4
6
8
10

153


Concrete Right After Pumping (76 F)
Concrete After 120 Mins. of Pumping (76 F)
Concrete Right After Pumping (47 F)
Concrete After 120 Mins. of Pumping (47 F)
Concrete Right After Pumping (102 F)
Concrete After 120 Mins. of Pumping (102 F)
0.098 Offset
Fresh SAM Number After Pumping
Fresh SAM Number Before Pumping
0
0.2
0.4
0.6
0.8

154