The Super Air Meter: A Test for Plastic Concrete

Braden Tabb, Robert Felice, John Michael Freeman, Robert Frazier, David Welchel, Morteza Khatibmasjedi, Jake LeFlore

Tyler Ley, P.E., Ph. D
Acknowledgements

- Oklahoma DOT
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- Kansas DOT
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Outline

• Introduction to Air entrained concrete
• Why is the SAM useful?
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
The Air-Entrainment Blues...

The most challenging aspect of concrete to get right is the air content.
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Large bubbles are the enemy!
What Do You Want in an Air-Void System?

• 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?

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What Do You Want in an Air-Void System?

• Volume of air provided is the same for both.
• Case B has a better air void distribution.
Why are large bubbles bad?

They leave the concrete and change your air volume

They don’t help with freeze-thaw durability

They reduce your strength more than smaller bubbles
What causes large bubbles?

- Admixture incompatibility
- Admixture/cement incompatibility
- Sand gradation
- Inadequate mixing
- Alkali content of binder
- Cement grinding aids
- Changes in temperature
- Pumping
How do you measure them?
Hardened Air Void Analysis

From Hover
Hardened Air Void Analysis

From Hover
normalized Air Content Fraction
Chord Size, microns

WROS Only
PC1 + WROS

small voids
Chord Size, microns
large voids

Freeman et al., 2012
• Spacing Factor – ½ of the average distance of an average sized void uniformly distributed in the paste

• Desired Value < 0.008 in (ACI 201)
normalized Air Content Fraction

Chord Size, microns

WROS Only
PC1 + WROS

small voids
Low spacing factor
High spacing factor
large voids

Freeman et al., 2012
ASTM C 457 Spacing Factor, in

Air %

WROS .45

ACI 201.2R

Small bubbles

Yes!

No!
ASTM C 457 Spacing Factor, in

ACI 201.2R

WROS 0.45

WROS 0.45 + PC1

Small bubbles

Yes!

Large bubbles

No!

Air %
You can’t tell the size of the bubbles by looking at the volume!!!

You can’t tell the size of the bubbles by looking at the volume!!!
Admixtures are not the same

Mix A
Small bubbles

Mix B
Large bubbles

0.40 w/cm

Yes!

No!
Mixtures with small bubbles

Freeman et al., 2012
Mixtures with large bubbles

Open symbols failed ASTM C666

Freeman et al., 2012
• We need to know the size of bubbles within the concrete

• The volume of air does not tell you anything about bubble size

• Although a hardened air void analysis can measure this, it is not practical to run regularly
Super Air Meter (SAM)

• We have modified a typical ASTM C 231 pressure meter so that it can hold larger pressures
• We have replaced the dial gage with a digital one
digital
gauge

six
clamps!
AASHTO TP 118

www.superairmeter.com
Air content given here
Pressure (psi) vs Time

- Top Chamber, $P_c$
- Bottom Chamber, $P_a$
- Equilibrium Pressure
release pressure in both chambers
Pressure (psi)

Time

Top Chamber, $P_c$
Bottom Chamber, $P_b$
Equilibrium Pressure

Diagram showing the pressure over time for the top and bottom chambers with equilibrium pressure.
Pressure (psi) vs Time

- Top Chamber, \( P_c \)
- Bottom Chamber, \( P_b \)
- Equilibrium Pressure

Air content and SAM number given here

SAM number

[Diagram of a chamber with a valve and air content representation]
How long does that take?

With just the SAM
Inexperienced user – 10 min
Experienced user – 7 min

With the CAPE
Inexperienced user - 7 min
Experienced user – 4.5 min
**Controlled Air Pressure Extender** aka **CAPE**

- **Step 1** (14.5 psi)
- **Step 2** (30 psi)
- **Step 3** (45 psi)
Discussion

The Super Air Meter gives you the air volume and the SAM number.

The CAPE is a portable air tank and regulators that can help you run the test faster.
Why is the SAM number useful?
This test takes 7 – 14 days

This test takes 5-10 minutes

92% Agreement

Yes!

No
10 DOTs over 100 field mixtures

YES!
SAM limit 0.20 – 68% agreement
SAM limit 0.25 – 79% agreement

NO
Discussion

The SAM number of 0.20 correlates well with the spacing factor of 0.008” for over 350 lab and field mixtures completed 13 different states.
This test takes 3.5 months

Yes!

This test takes 5 - 10 minutes

80% agreement w/ 0.20 limit
89% agreement w/ 0.25 limit
This test takes 3.5 months

69% agreement

Yes!

This test takes 7 - 14 days
Discussion

A SAM number of 0.20 correlates better to rapid freeze thaw durability than a spacing factor of 0.008”. 
Admixtures are not the same. Mix A has small bubbles, while Mix B has large bubbles. The graph shows that 0.40 w/cm is not the same. Mix A meets the requirements, while Mix B does not.
Durability Factor (%) vs. SAM Number from Super Air Meter

- Mix A: Small Bubbles
- Mix B: Large Bubbles

Yes! and No! indicators on the graph.
Why is this useful?

- The SAM can tell us about the quality (size and spacing) of our air void system before the concrete sets.
- It can tell us about the freeze thaw durability of our air void system.
- It can also tell us if we will have air void stability problems during our mixture design process!!!!
Why is this useful?

This can give you important testing information that was almost impossible to get in the past

This is helpful when:

- mixtures are designed in the lab
- mixtures are placed in the field
- trial batching in the field
- troubleshooting field problems
- measuring variation in materials
How do I do this?
An example

• Mix 1 - SAM number of 0.22 and an air content of 5%

• Mix 2 - SAM number of 0.40 and an air content of 6%
This is crazy valuable!!!!!!
Discussion

By plotting your data on the SAM Curve you can immediately tell if your air void system is made of large or small bubbles.

This immediate feedback can be used to troubleshoot field issues and give you feedback on your concrete mixture design.
The following states have a SAM

- Michigan (5)
- Kansas (16)
- Utah
- Colorado (2)
- Iowa (2)
- Illinois (5)
- Indiana (2)
- Wisconsin (4)
- Massachusetts
- Idaho (2)
- Tennessee (2)
- Pennsylvania
- Missouri (2)
- California
- N. Carolina (3)
- N. Dakota
- Oklahoma (10)
- Nebraska (3)
- Ohio (5)
- Minnesota (3)
- Texas (2)
- FHWA (6)
- Georgia
- New Jersey
- New Mexico
- New York (5)
- S. Dakota
- Mississippi
- Iowa (2)
- Oregon
- Manitoba (5)
- Ontario (2)
- England
- Poland (2)
<table>
<thead>
<tr>
<th>Test methods</th>
<th>Parameter</th>
<th>COV</th>
<th>Agreement with durability factor of 70 in ASTM C 666</th>
<th>Time to complete the test</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHTO TP 118</td>
<td>SAM number (OSU)</td>
<td>17.1</td>
<td>80%</td>
<td>10 min</td>
</tr>
<tr>
<td></td>
<td>SAM number (workshop**)</td>
<td>18.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTM C 457</td>
<td>spacing factor</td>
<td>20.1</td>
<td>69%</td>
<td>7 days</td>
</tr>
<tr>
<td>ASTM C 666</td>
<td>durability factor*</td>
<td>22.7</td>
<td>-</td>
<td>3.5 months</td>
</tr>
</tbody>
</table>

* assuming a durability factor of 75 and method B
** includes all participants
Discussion

The variability of SAM is similar to the variability in the hardened air void analysis and rapid freeze thaw testing and the test can be run in the field on fresh concrete in less than 10 min.
I don’t think it is a coincidence that the variability is so similar between the three different methods.

Each test is designed to investigate the air void distribution. Air void distribution may be more variable than other concrete properties such as compressive strength.
How do you specify the SAM?

1. Replace the air meter with the SAM in the field
2. Use the SAM during the mixture design stage and validate in the field.
SAM replaces air meter

Air content must be above 4%

- Bonus
- Full Pay
- Deduct
- Remove and Replace
SAM used during mixture acceptance

- During mixture design stage run trial batches with air < 5% and SAM number must be < 0.25.
- Test air as per typical practice.
- Validate that SAM < 0.25 and air > 4% once a day or every 1000 yds in the field.
I need your help

Taking the industry from a horse and buggy to an internal combustion engine is not easy.

Try the SAM!
Ask questions!
Give suggestions

Share what you learn here with others
Help others become knowledgeable of the SAM
I need your help

Help extend my Pooled Fund Study. We need 5 more states. TPF-5(97)

Myers Assoc. has a SAM in the exhibitor hall.

Request a SAM from FHWA

AASHTO Webinar this Thursday (10/20/16)
Conclusion

• Large bubbles are the enemy!
• Air volume does not tell you bubble size.
• The SAM can measure the volume and size distribution of the bubbles in fresh concrete
• This is helpful for making your air more consistent and ensure freeze thaw durability
Conclusion

- A SAM number of 0.20 seems to correspond to a spacing factor of 0.008”
- Over 90% of the lab and field data is correctly separated with this limit
- The SAM number correlates with ASTM C666 testing
- The SAM has been investigated by a number of others and all have found similar correlations
Questions???
Tyler.ley@okstate.edu
www.tylerley.com
www.superairmeter.com
What if my SAM number is too high?

• Add more air
• Change mixture proportions
• Change mixing/batching operations
How does the SAM work?
synthetic AEA

pressure step 0
atmospheric pressure
pressure step 1
pressure step 3
pressure step 4
pressure step 5
Atmospheric pressure
pressure step 0
atmospheric pressure
What is happening?

• As you increase the pressure you are dissolving the small bubbles into solution and then they do not immediately come back when you decrease the pressure.

• Notice that these bubbles are not close to one another.
Why is this happening?

• According to the Laplace – Young equation smaller bubbles have higher pressures in them than larger bubbles

\[ P = P_0 + \frac{4\sigma}{d} \]

• This is caused by the differences in curvature of the bubble wall
Assumes $\sigma = 72$ dynes/cm

Atmospheric pressure
Why do the bubbles dissolve?

- Henry’s Law states that at a certain pressure that a certain amount of the gas would rather dissolve in the liquid than remain a gas

\[ p = k_H c \]

- \( p \) = pressure
- \( c \) = concentration
- \( k_H \) = Henry’s Law constant
More pressure experiments

• We ran additional experiments where we tracked individual bubbles every 5 psi from atmospheric until 35 psi.

• We looked at two different situations:
  1. High spacing factor (bubbles far apart)
  2. Low spacing factor (bubbles close together)
Atmospheric Pressure

High spacing factor

Atmospheric Pressure

35 psi
other pressures not shown

Returned to Atmospheric Pressure

Low spacing factor
Air Bubble Diameter ($\mu m$) vs. Applied Pressure (psi)

- **High spacing factor**
- **Low spacing factor**

*Bubble dissolves*
Results

The bubbles in the high spacing factor system (bubbles far apart) almost entirely dissolve and do not come back.

The bubbles in the low spacing factor system (bubbles close together) do not dissolve very much.
Results

• If you have a high spacing factor (bubbles far apart) then the bubbles dissolve from the first set of pressures and they won’t be around to resist the second pressure step.

• This will cause a high SAM number.

• If you have a low spacing factor (bubbles close together) then the bubbles will only dissolve a little and the first and second pressure step is about the same.

• This will cause a low SAM number.
Results

• We did a lot of testing with a lot of different materials to find how this pressure change corresponded to spacing factor.
Case Studies from FHWA Mobile Concrete Lab

These slides are from Jagan Gudimettla
Air Void System - AVA

FHWA Mobile concrete lab

Air Void Analyzer (AVA)

Slide from Jagan Gudimettla
Air Void System – SAM vs. AVA

FHWA Mobile concrete lab

Slide from Jagan Gudimettla
Spacing Factor (AVA), in

Super Air Meter (SAM) Number

86% agreement

FHWA Mobile concrete lab