TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): Oklahoma Department of Transportation

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *TPF-5(297)*	**Transportation Pooled Fund Program - Report Period:** X Quarter 1 (January 1 – March 31) O Quarter 2 (April 1 – June 30) O Quarter 3 (July 1 – September 30) O Quarter 4 (October 1 – December 31)	
Project Title: **Improving Specifications to Resist Frost Damage in Modern Concrete Mixtures**		
Name of Project Manager(s): **Tyler Ley**	**Phone Number:** **405-744-5257**	**E-Mail** Tyler.ley@okstate.edu
Lead Agency Project ID: **TPF-TPF5(297)RS / JOB PIECE 30802(04)**	**Other Project ID (i.e., contract #):** AA-5-52974	**Project Start Date:** March 10, 2014
Original Project End Date: February 28, 2017	**Current Project End Date:**	**Number of Extensions:**

Project schedule status:

On schedule ☐ On revised schedule ☐ Ahead of schedule X Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Percentage of Work Completed to Date
$572,500	$330,000	63%

Quarterly Project Statistics:

Total Project Expenses and Percentage This Quarter	Total Amount of Funds Expended This Quarter	Total Percentage of Time Used to Date
$30,000	$30,000	75%

Project Description:

Concrete can be damaged when it is 1) sufficiently wet (has a high degree of saturation) and 2) is exposed to temperature cycles that enable freezing and thawing. The damage that occurs due to freezing and thawing can lead to premature deterioration, costly repairs, and premature replacement of concrete infrastructure elements. Current specifications for frost durability are largely based on work completed in the 1950s, and while this work included many landmark discoveries (Kleiger 1952, 1954). This work from the 1950s may not be representative of materials used in modern concrete mixtures. Results from recent studies suggest that there are several ways in which frost damage can be reduced through new tests and improve specifications that can lead to extended service life of concrete infrastructure.

The goal of the research is to produce improved specifications, and test methods; while, improving the understanding of the underlying mechanisms of frost damage. Specifically, this work will seek to develop new test procedures that may be faster and/or more reliable than the existing methods. The objectives of this project are:

- Determine the necessary properties of the air-void system to provide satisfactory frost durability in testing of laboratory and field concretes with different combinations of admixtures, cements, and mixing temperatures
- Determine the accuracy of a simple field test method that measures air void system quality with field and laboratory concrete
- Determine the critical combinations of absorption and the critical degree of saturation on the frost durability in accelerated laboratory testing
- Establish new test methods and specifications for fresh and hardened concrete to determine frost durability and field performance

In addition, a streaming lecture series on freeze-thaw durability will be generated as part of this work.

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

Task 1: Literature Review and Development of the Testing Matrix (OSU and Oregon State)

In this task the research teams will review the existing literature and determine a testing matrix to cover the necessary variables. Work is needed to understand how different mixture components impact the air entrainment system and subsequently the frost durability of concrete. These variables can lead to changes in AEA effectiveness and their impact needs to be quantified with ASTM C 666 testing. As part of this task we will work with our project oversight committee to establish a set of materials and a testing matrix that can be used for the entire study. The decisions used in developing this test matrix will be made based on literature review, previous research by the PIs and the needs identified by the study advisory discussions.

The testing matrix was discussed with the research oversight committee. The team first looked at mixtures for bridge decks and then moved to mixtures for pavements. Here is an overview of the mixtures:

Limestone aggregate and natural sand from Oklahoma will be used for these mixtures. Both aggregates have been shown great freeze thaw field performance in the laboratory and the field. A mixture with 20% class C fly ash will be investigated with 6.5 sacks of total cementitious content and a w/cm of 0.45. A wood rosin AEA will be the primary admixture investigated as it is the most widely used AEA. However, select mixtures will be investigated with synthetic AEA. These AEAs will be used to produce mixtures with different spacing factors and air content. These samples will be investigated in a number of the freeze thaw tests in the project. Next, a mixture with 0.40 w/cm will be investigated with the same AEA. After that mixtures with high range water reducers will be investigated with 0.40 and 0.35 w/cm. A few mixtures with different high range water reducer dosages will also be investigated.

On this project over 100 concrete mixtures have been investigated in the laboratory. The work has been completed for the hardened air void analysis and the rapid freeze thaw testing. In addition, two SAMs were completed on each mixture.

Repeatability testing is being completed on mixtures at OSU with four expert SAM operators. This testing has gone well and 10 mixtures have been completed. The team hopes to have a large round robin testing at OSU of the SAM operators.

The research team also looked at concrete before and after a concrete pump with the SAM. This data will be presented in more detail in future reports.

In addition, the SAM has been used to investigate repair concretes that use calcium sulfoaluminate, calcium aluminate, and alkali activated binders. The results show that the SAM measurement seems to work well with these materials except for the alkali activated binders and shows good correlation with the durability factor from the ASTM C 666 test. The hardened air void analysis is still ongoing.

The team plans to investigate how the SAM needs to be modified for use with light weight aggregate.

95% complete (This task will not reach 100% until the end of the project as changes are continually made to the testing matrix.)

Task 2: Sample Preparation (OSU and Oregon State)

All of the mixtures that represent bridge decks and pavements have been completed at OSU and then shipped to Purdue for testing. Mixtures with different amounts of superplasticizers and air entraining agents have been investigated. Mixtures are also being complete to look at different dosages of superplasticizer and also some mid-range water reducers. Over 100 mixtures have been investigated.

Concrete repair materials have been investigated with the SAM. The SAM number shows good correlation with the ASTM C 666 durability factor for all materials tested except for alkali activated cements. These materials use very little water and instead use a chemical activator. The chemical activator likely changes the solubility of the air in the solution. This probably explains why the SAM test does not work with these materials. The samples are still being polished for hardened air void analysis.

The SAM test has also been used to look at some repair grouts. This will be investigated in future testing.

The research team has also started using four experienced users to investigate concrete mixtures with the SAM. This is done to examine the repeatability of the test method. So far nine mixtures have been completed and the data is described in an upcoming section. Mixtures have also been completed before and after a concrete pump. More mixtures are planned for the upcoming quarter.

70% complete

Task 3: Validation of the Super Air Meter (OSU)

In this task the Super Air Meter (SAM) will be evaluated in laboratory and field mixtures. The laboratory mixtures to be investigated include: aggregate with high aggregate correction factor, light weight aggregate, hot weather concrete, cold weather concrete, and any other items that the research oversight committee feels is important. In addition a number of mixtures will be investigated in the field. This will be done by visiting local ready mix and central mix batch plants to take samples.

Over 100 laboratory mixtures, 50 field mixtures, and over 30 mixtures by FHWA Turner Fairbanks Laboratory has been completed and the results are shown in Fig. 1. The data shows that the SAM does a good job of predicting the spacing factor for the majority of the mixtures investigated. The SAM limit of 0.20 has shown a correlation to a spacing factor of 0.008" 94% of the time. Data has also been included for the correlation between the SAM number and the durability factor. This data is included in Fig. 2. These results show that there is a 80% correlation between the SAM number of 0.20 and durability factor of 70% and a correlation of 89% for a SAM number of 0.25. This is an important finding as this confirms that the SAM number correlates well with the freeze thaw durability of the concrete. As more tests are completed the data will be added to these plots.

For all of these mixtures at least two different SAMs are being investigated in order to collect the precision and bias information needed for the AASHTO test method. To further investigate the variability of the test method research team is using four local SAM experts to simultaneously investigate the same concrete mixtures. These results so far for nine concrete mixtures is shown in Table 1 and 2. The testing shows that the method has an average standard deviation of about .024 and a coefficient of variation of 22%. These results are more variable than the measurement of the air content (COV = 2%) but are less variable than the precision and bias that is reported for the hardened air void analysis (COV = 27%) and the air void analyzer (COV = 43%). All of this data will be used to contribute to the precision and bias statement for the SAM. The research team still plans on holding a large round robin at OSU that will involve training of operators and a discussion over the mechanisms of the SAM and then the investigation of concrete mixtures. Each of the meters will be investigated, their calibration will be checked, and then they will be used to investigate concrete. This will likely take place in Chicago in June or July. Details are being planned.

Testing has also been done with the SAM to investigate a number of repair materials. The testing is completed and the SAM shows good performance with all the materials except the alkali activated binders. As explained early in the report this can be explained. The freeze thaw testing is complete for a large number of these materials but the hardened air void analysis is not. This is a good validation for the SAM and allows further insights into the performance. These samples are being completed and will also be used to evaluate the tool for totally different binder systems.

In addition, the SAM has been provided to the following partners for their use: Oregon State, Iowa State, Purdue, Iowa, Nebraska, Kansas, North Dakota, Illinois, Oklahoma, Pennsylvania, Minnesota, Idaho, New Jersey, and Wisconsin. The following states have either already provided or have agreed to supply field data: Iowa, Michigan, Wisconsin, Minnesota, North Dakota, Kansas, Nebraska, Colorado, Pennsylvania and Utah. In addition, the FHWA mobile concrete lab has supplied samples from a number of different states. The research team is working on the hardened air void analysis but is somewhat behind. This will be a big focus for the next quarter.

Individual results from field concrete cast and then the hardened air void analysis was independently completed by Pennsylvania DOT is shown in figs. 3 and 4. Figure 3 shows the spacing factor versus the air content. This graph shows that only using air volume is not enough to ensure that you have a quality air void system. However, fig. 4 shows that when you compare the SAM number and spacing factor then there is a great correlation. This matches the correlation shown in Fig. 1 and is a validation of the test method. A similar plot for other state DOTs is shown in Fig. 5. This figure shows an overall agreement between the previous lab and field testing and results by different states.

New supplemental equipment has been developed to speed the test from 8-10 minutes to 5-6 minutes called the CAPE (Controlled Air Pressure Extender). Each pooled fund member will be receiving a CAPE as part of the project. We have supplied a few states a CAPE and will send out several more soon. Also, there is a new air pressure adjustment valve that has been added to the SAM. This makes it easier for users to get the exact pressure in the test and they will no longer have to use the Schrader valve to adjust the pressures. This will speed the test up and make it easier to run. Each state will also receive one of these valves. This will likely be shipped with the CAPE.

Finally, a new method has been developed to investigate the data from the SAM and determine the average size of the bubbles in the air void system. This is found by plotting the air content on the x-axis versus the SAM number on the Y-axis. This graph is shown in Fig. 6. Typical curves for poor void size and spacing is shown as the upper curve. The lower curve shows a good void size and spacing. This means that if you plot the SAM number and air content on the graph and the point falls near the lower curve then you have a good void size and spacing and you will need a minimum air content to provide freeze thaw durability. If your data point plots near the top line then you have a coarse air void system. This means that you can take the data from the SAM and instantly determine the characteristic of your air void system. Changes can then be made in the design of the concrete mixture to change the location of the mixture on this curve. This is an important tool for our industry to help troubleshoot problems in the field, and help guide practitioners on how to design their concrete mixtures.

71% complete

Task 4: Creation of an AASHTO Test Method and Specification for the SAM (OSU)
The SAM test method has been published as AASHTO TP 118. This is a great accomplishment.

Work still needs to be done to update the variance of the test method. Also, some text needs to be added about the length of time between the first and second pressure step. The field testing has shown that if the time between the first and second pressure step is more than 15 minutes then this can alter the test. The only way this would happen is if someone started running the test and then took a break for more than 15 minutes and then completed the test. We are gathering data now for the precision and bias statement and we hope to be able to add light weight aggregate to the document.

80% complete

Task 5: Use of X-Ray Tomography of Air Voids and Frost Damage (OSU)

Researchers at OSU have developed nondestructive techniques to examine microscopic air voids in fresh and hardened concrete by using a X-ray micro computed tomography (mCT) scanner. This is a powerful technique that allows measurements to be made not previously possible. The research team has developed techniques to image water movements and have access to a freezing stage. By combining this information about the void distribution, the moisture content and distribution, and then being able to image the damage that occurs from freezing is a powerful tool. These observations can lead to ground breaking insights into the mechanisms of frost damage and how it can be avoided.

The experimental methods are largely finished and a paper is being authored over the work. A rough draft of the paper has been developed and is being reviewed. Work has also been completed over using mCT to image samples both before and after freezing. We have successfully aligned the data sets and we can clearly show where there were existing cracks in the sample and how these cracks extend after a single freezing cycle. Some results have been included in the attached figures. Samples have been investigated with a poor air void system and a high degree of saturation. This is the worst case and it has caused damage.

Work has also been done to investigate the mechanisms of salt scaling. Samples were imaged with the mCT scanner before and after during freezing events. These results show that damage can be observed with this method and provide quantitative mapping of the location of crack propagation. A student has completed his thesis on this topic, a journal paper is under preparation, and a poster was presented at the American Ceramics Society – Cements Division meeting. This poster was given an award for meritorious achievement. The poster was included in a previous quarterly report.

Progress 55%

Task 6: ASTM C 666 (OSU and Oregon State)

The primary test method used to investigate the frost durability of the concrete will be the ASTM C 666 test. This test is the most widely recognized test to investigate the rapid deterioration from freezing and thawing. As many mixtures will be investigated with this test as possible. As part of this task the specimen absorption and desorption of the samples will be investigated using a modified form of ASTM C 1585. The impact of wetting and drying will also be investigated. While the team realizes that the ASTM C 666 is a well-respected test, they feel that the three months required to complete the test is too long. The research team plans on using this information to help find a shorter test with the same rigor.

A new chamber has been purchased and a significant amount of C 666 testing has been completed. A summary of the test results are shown in Fig. 2. These results show an 80% agreement with a SAM number of 0.20 and an 89% agreement if a SAM number of 0.25 is used. This difference was discussed on the conference call and a recommendation was made to stay with the 0.20 limit as it was conservative. A proposed specification has been included in this document for the implementation of the SAM.

Progress 70%

Task 7: Absorption and Desorption (Oregon State)

During this task the research team will perform desorption/sorption analysis on selected mixtures prepared in Task 2. For the sorption tests 100 mm diameter samples will be used that are 50 mm in thickness. The samples will then be placed in fluid according to a modified version of ASTM C 1585 to determine the degree of saturation over time. In addition, the complete degree of saturation will be determined using vacuum saturation.

The sampling and testing protocols have been developed (as illustrated in Fig. 7) and the samples have completed conditioning at 50% and 75% relative humidity for the sorption tests. Sorption testing on both samples conditioned to 50% and 75% RH is completed for the first half of the samples sent to Purdue. The samples in the last two series were tested in late 2015. Upon oven drying, the results of this test will be used to determine the nick point (S_n) (the point between initial and secondary sorption) and the slope of the secondary sorption curve, which are essential for predicting long term performance. The drying test has been completed for all samples for 50 and 75% RH and the results are in the analysis stage. Additionally, dynamic vapor sorption (DVS) testing has been completed for 3 of the 4 planned specimens. The last specimen will complete DVS testing in the next quarter in early 2016. The results are in the analysis stage.

The LGCC is being redesigned to accommodate larger samples for future use.

Progress 80%

Task 8: Degree of Saturation and Damage Development (Oregon State)

Samples prepared in Task 2 will be saturated to different degrees of saturation and the freeze-thaw tests will be performed with the samples in a sealed condition. Freeze-thaw tests have been performed on 11 samples with 50 mm thickness and 68 mm diameter using a new Longitudinal Gaurded Comparitive Calorimeter (LGCC) setup with acoustic emission sensing to detect damage (Figure 8). This test setup is capable of measuring temperature throughout the setup height to determine heat flow through the sample during each freeze-thaw cycle. Additionally, the setup is equipped with 2 acoustic emission sensors which can passively detect acoustic events as well as actively measure pulse velocity across the sample. The changes in pulse velocity throughout the freeze-thaw process can then be directly correlated to damage development in the concrete. Results from this test will be used to identify the critical degree of saturation with the express purpose of relating the critical degree of saturation to the quality of the entrained air system (for example the air void spacing). Information from this test will be used in conjunction with the results from Task 7 to determine if the air void system alters the time required to reach a critical degree of saturation (which is hypothesized with a higher SAM number corresponding to a lower S_{CRIT}). Additionally, a series of 3 cylinders will be used to determine the resistivity and degree of saturation over time of samples submerged in pore solution (to prevent alkali leaching). Additional resistivity tests will be performed at various ages and degrees of saturation on samples from a variety of tests in order to determine if a relationship exists to correlate resistivity and sorption.

The testing protocols have been developed (Figure 6). DOS cylinders from all 34 total mixtures have been tested and the results have been used to determine the degree of saturation for cylinders in the corresponding resistivity tests. Both short and long term resistivity tests have concluded for all samples. The degree of saturation and resistivity were monitored over time and are displayed in Figure 9 and Figure 10 respectively. Experimental nick point values have been compared to theoretical values and have been related to both air volume and SAM numbers. This was discussed in the conference paper included in a previous quarterly report. Further work is underway to investigate the relationship between formation factor at various degrees of saturation and air parameters in order to more easily assess durability.

All Freeze-Thaw samples have been cut, cored, and conditioned for testing in the LGCC (Figure 8). This includes additional samples outside of the testing scope that will be available for future testing if necessary. The additional samples have been sent to Oregon State University where the work will continue. Mixture with different air contents and varying SAM numbers have been tested at approximately 100%, 95%, and 90% degrees of saturation. Each sample was exposed to three freeze-thaw cycles over the course of five days, with pulse velocity measurements taken hourly. Results from these tests have been analyzed. An example of the acoustic emission data output is shown in Figure 12, which shows the acoustic emissions recorded by two opposing sensors on three specimens within the same mixture, conditioned to all three saturation levels. It is clear that for this fully saturated sample, cracks are emitting due to freeze-thaw damage over the course of 3 thermal cycles. This activity is reduced with lower levels of saturation. Figure 13 shows the acousto-ultrasonic testing results for the same three specimens. Damage in the concrete matrix (a reduction in the elastic modulus) can be correlated to the reduction in pulse velocity after each freezing cycle. It is evident that highly saturated samples show a drastic reduction in pulse velocity (large amounts of damage) while the sample closer to the critical degree of saturation shows little reduction in pulse velocity (low levels of damage). This method of calculating damage index was used to ultimately determine whether a relationship exists between the critical degree of saturation and properties of the air void system quality (SAM number). Ultimately, it was determined that specimens with higher quality air void systems (lower SAM numbers) are associated with higher thresholds for the degree of saturation necessary for freeze-thaw damage development (the critical degree of saturation). This finding can be used to create performance-based specifications for concrete durability, considering the critical degree of saturation as a limit state for service life. This result is shown in Figure 14 and will be explained further in a journal paper which is currently in progress.

Progress 90%

While the additional work has been completed the team would like to discuss additional research directions that should be pursued for the development of this model and use in practice.

Task 9: Rate of Damage Analysis (Oregon State)

This task will combine acoustic emission data and X-ray mCT and neutron tomography to detect cracking and also image the location. This will be done in samples with different quality of air void systems and with different paste quality and saturation level.

Purdue provided 12 samples that the team at OSU scanned at several micron resolution and then sent back to Purdue so that they could investigate them in the neutron beamline at NIST. In the beamline the samples were flooded with water and then freezing cycles were used to try and create damage in the samples. The samples have been sent back to OSU and scanned again to investigate the amount of cracking. This technique can show the extensive damage in the samples with high levels of DOS. The analysis can separate the air voids, aggregates, cracks, and paste. It can clearly show where the cracks are located before and after the freezing events. This should begin to provide useful observations for the project and provide a more basic understanding of freeze thaw damage.

A fracture based model is being expanded on that can be used to relate the acoustic activity, damage assessment and fracture modeling. Also, work is now underway to image the movement of solution within concrete with X-ray mCT. This technique has been completed and is being submitted for publication. The next step will be to determine at what level of saturation the voids begin to fill in the sample and then how the fluid responds when it is frozen.

Progress 43%

Task 10: Technology Transfer (OSU and Oregon State)

A portion of this project will be dedicated to development of a strong educational technology transfer program. The PI's propose the development of a short course that utilizes streaming video (and could be placed on a DVD for widespread dissemination). No progress has been made on this task. This will be completed late in the project so that the latest findings can be shared with the audience.

Progress 0%

Task 11: Final Report (OSU and Oregon State)

This task will be completed in the final quarter of the project.

Progress 0%

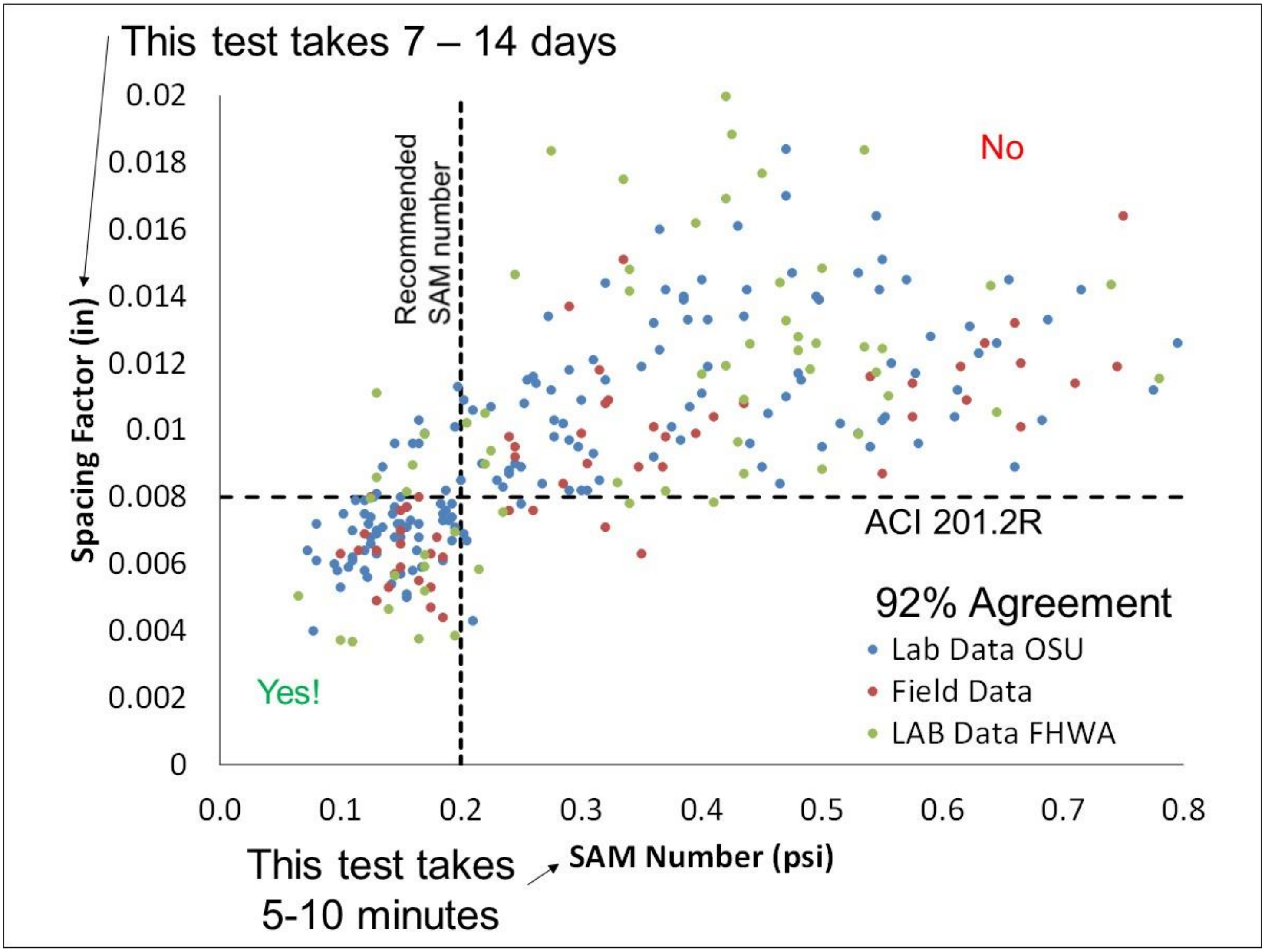


Figure 1 – A combination of OSU lab data, Oklahoma field data, and FHWA lab data.

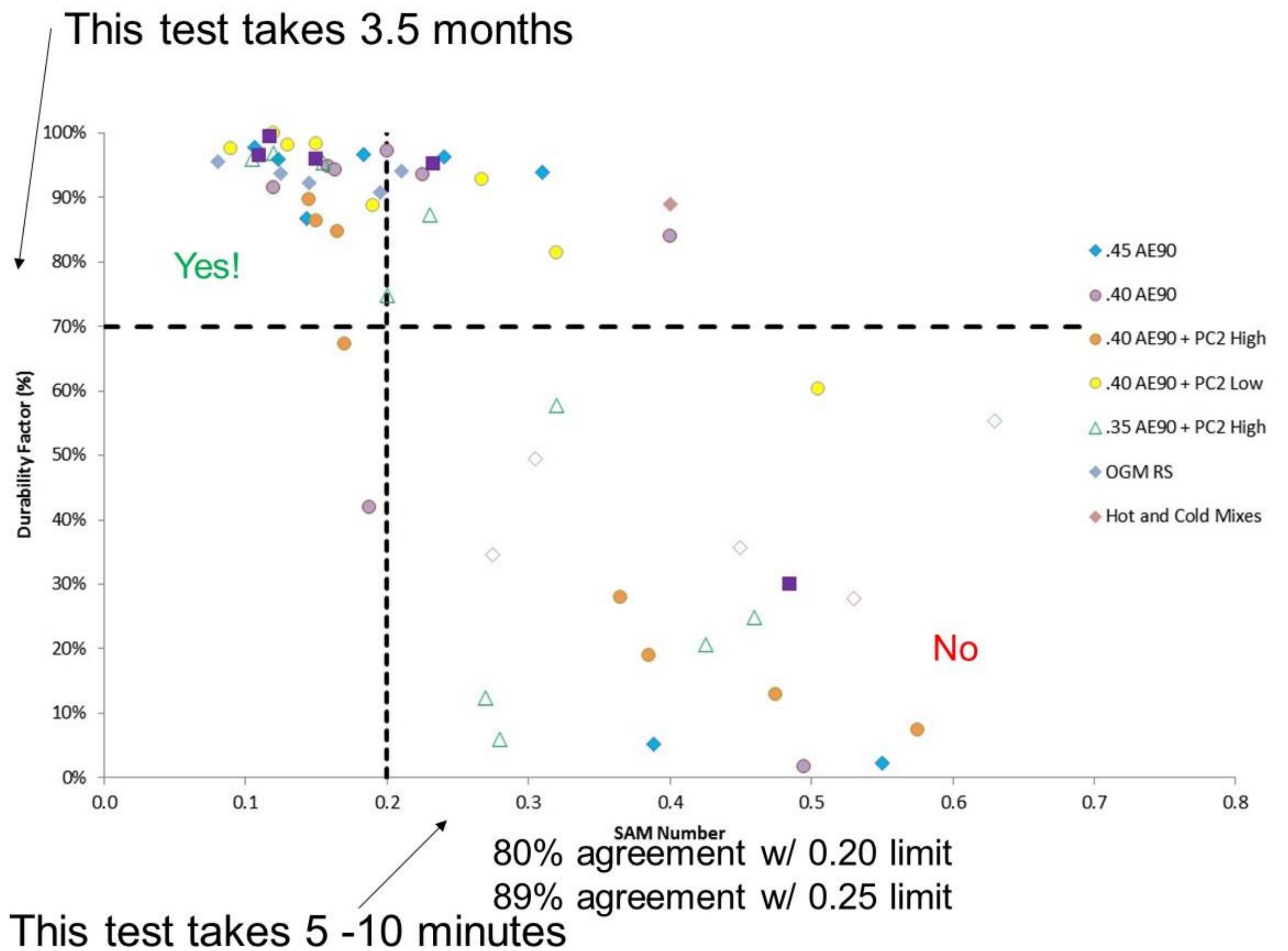


Figure 2 – A comparison of ASTM C 666 durability factor and the SAM number. There is an 80% agreement with a SAM limit of 0.20 and a 89% agreement with a SAM limit of 0.25.

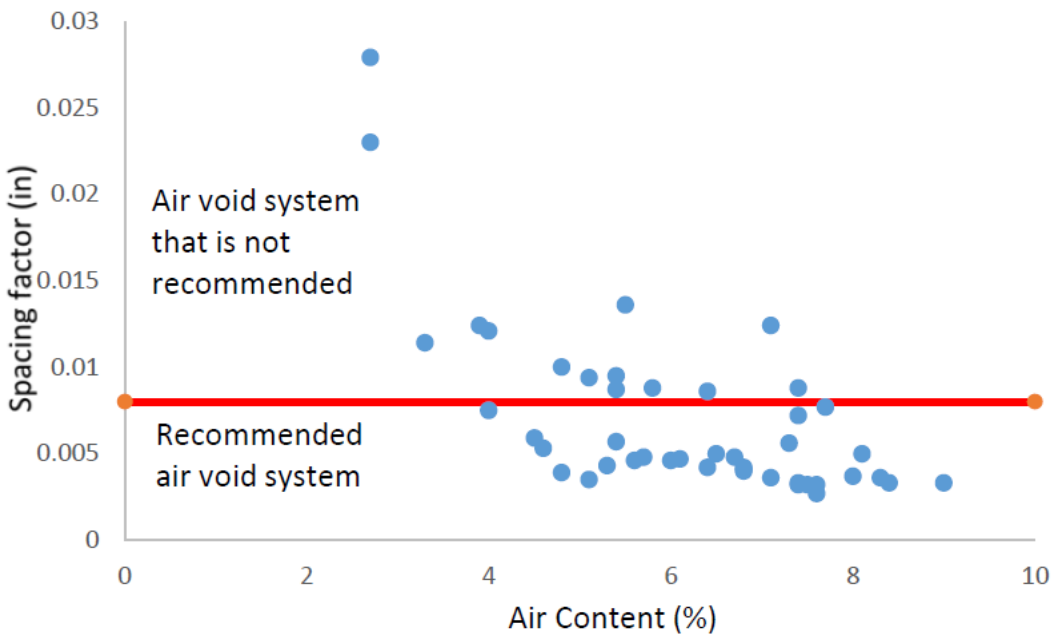


Figure 3 – A comparison of the air content versus the spacing factor for the field data from Pennsylvania.

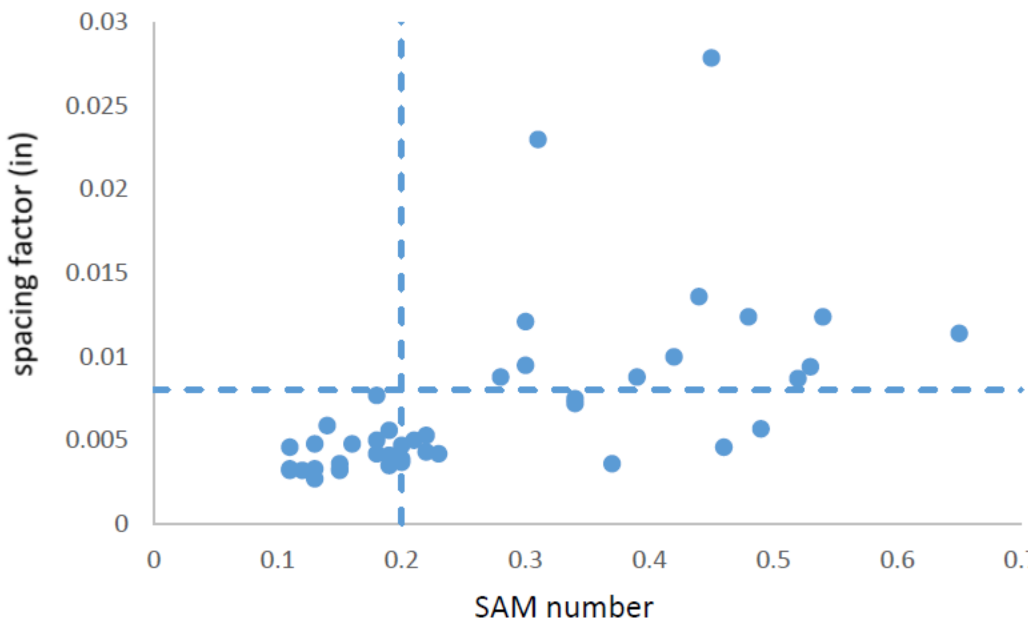


Figure 4 – Comparison of the SAM number and spacing factor for 47 field samples from Pennsylvania DOT. A SAM limit of 0.20 and a spacing factor limit of 0.008" is shown.

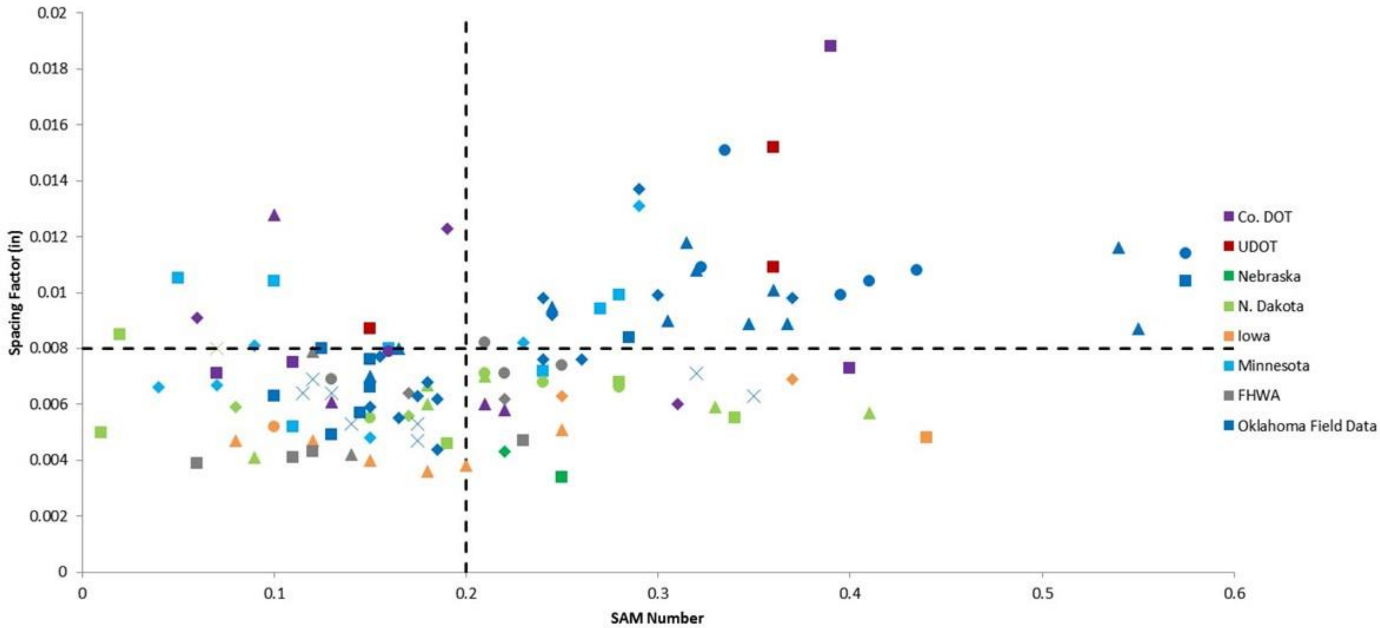


Figure 5 – Field testing data comparing the SAM number to the spacing factor for field mixtures from a number of different states with the spacing factor and SAM number compared.

Table 1 – The air content and SAM number for nine different mixtures for multiple operators.

		Operator				average	standard deviation	COV
		A	B	C	D			
Mix 1	Air	7.7	7.7	8		7.80	0.17	2.2
	Sam	0.15	0.13	0.10		0.13	0.025	19.9
Mix 2	Air	7.80	7.60	7.70	8.00	7.78	0.17	2.2
	Sam	0.05	0.07	0.10	0.05	0.07	0.024	35.0
Mix 3	Air	7.90	7.90	7.70		7.83	0.12	1.5
	Sam	0.14	0.12	0.14		0.13	0.012	8.7
Mix 4	Air	7.80	7.80	8.00	7.70	7.83	0.13	1.6
	Sam	0.05	0.05	0.00	0.03	0.03	0.024	72.7
Mix 5	Air	7.70	7.80	7.70	7.70	7.73	0.05	0.6
	Sam	0.10	0.15	0.11	0.10	0.12	0.024	20.7
Mix 6	Air	4.30	4.30	4.30		4.30	0.00	0.0
	Sam	0.22	0.25	0.23		0.23	0.015	6.5
Mix 7	Air	5.70	5.40	5.50	5.50	5.53	0.13	2.3
	Sam	0.15	0.16	0.15	0.10	0.14	0.027	19.3
Mix 8	Air	4.10	4.20	4.30		4.20	0.10	2.4
	Sam	0.32	0.34	0.36		0.34	0.020	5.9
Mix 9	Air	4.00	4.10	3.70		3.93	0.21	5.3
	Sam	0.40	0.46	0.37		0.41	0.046	11.2

Table 2 – The average standard deviation and coefficient of variation for the data from Table 1 as well as the coefficient of variation for the SAM, air content, spacing factor from ASTM C457 and the spacing factor from the AVA.

	average standard deviation	average COV
Air content	0.12	2.0
SAM (concrete)	0.024	22.2
ASTM C 457 (spacing factor)*		27
AVA (spacing factor)**		43

* ASTM C 457

** Distlehorse and Kurgan 2007

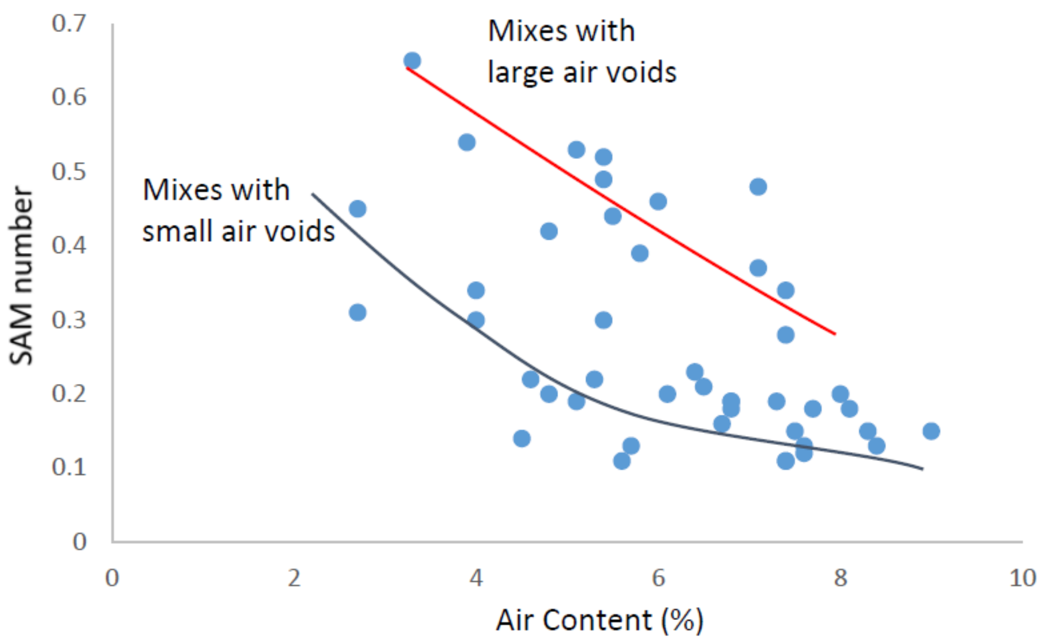


Figure 6 – A comparison of the air content and SAM number. The top line shows mixtures with coarse air voids and the bottom line shows mixtures with fine air voids. By plotting the data in this way it can tell the operator quickly what the overall size distribution of the void system is.

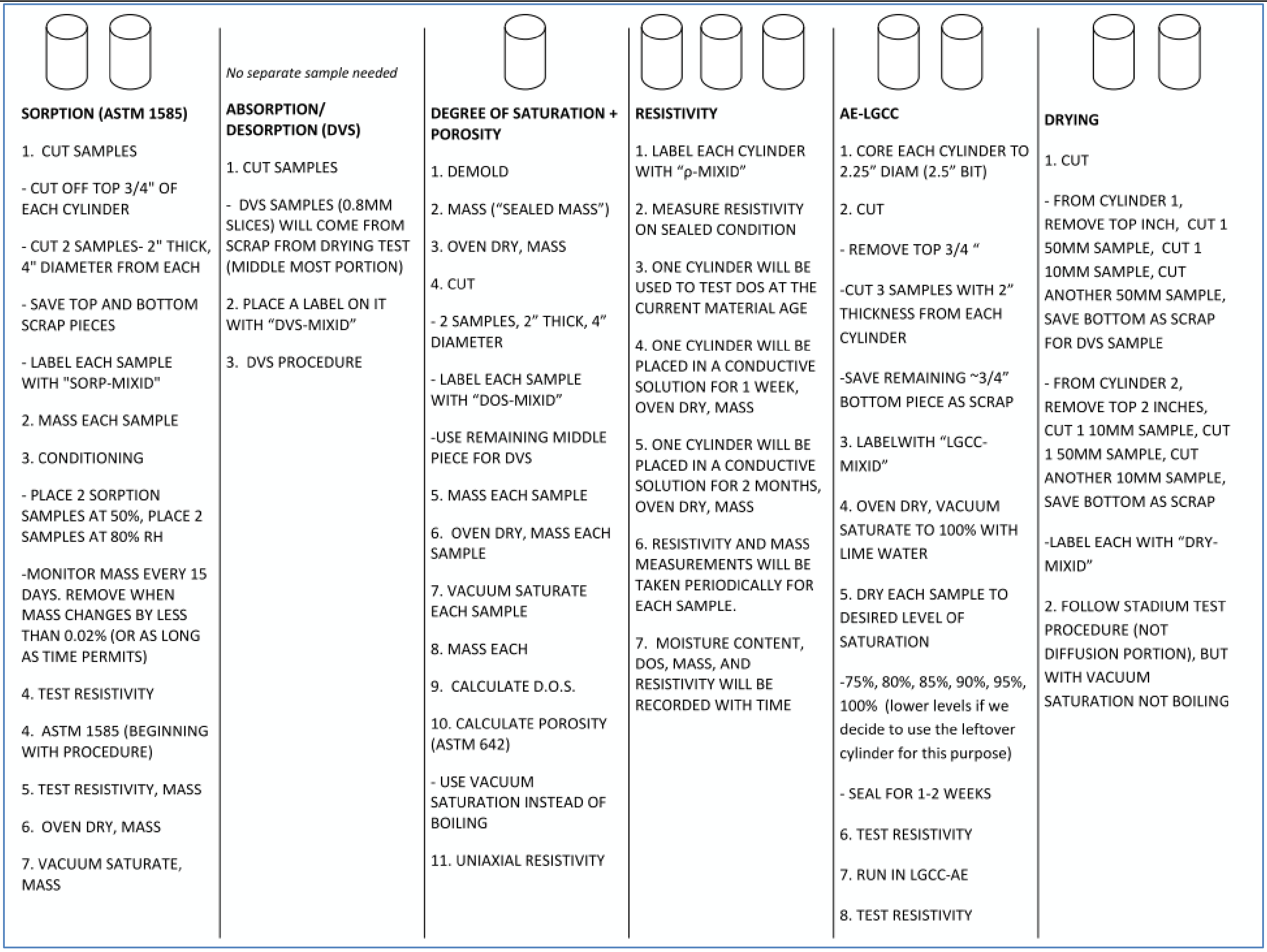
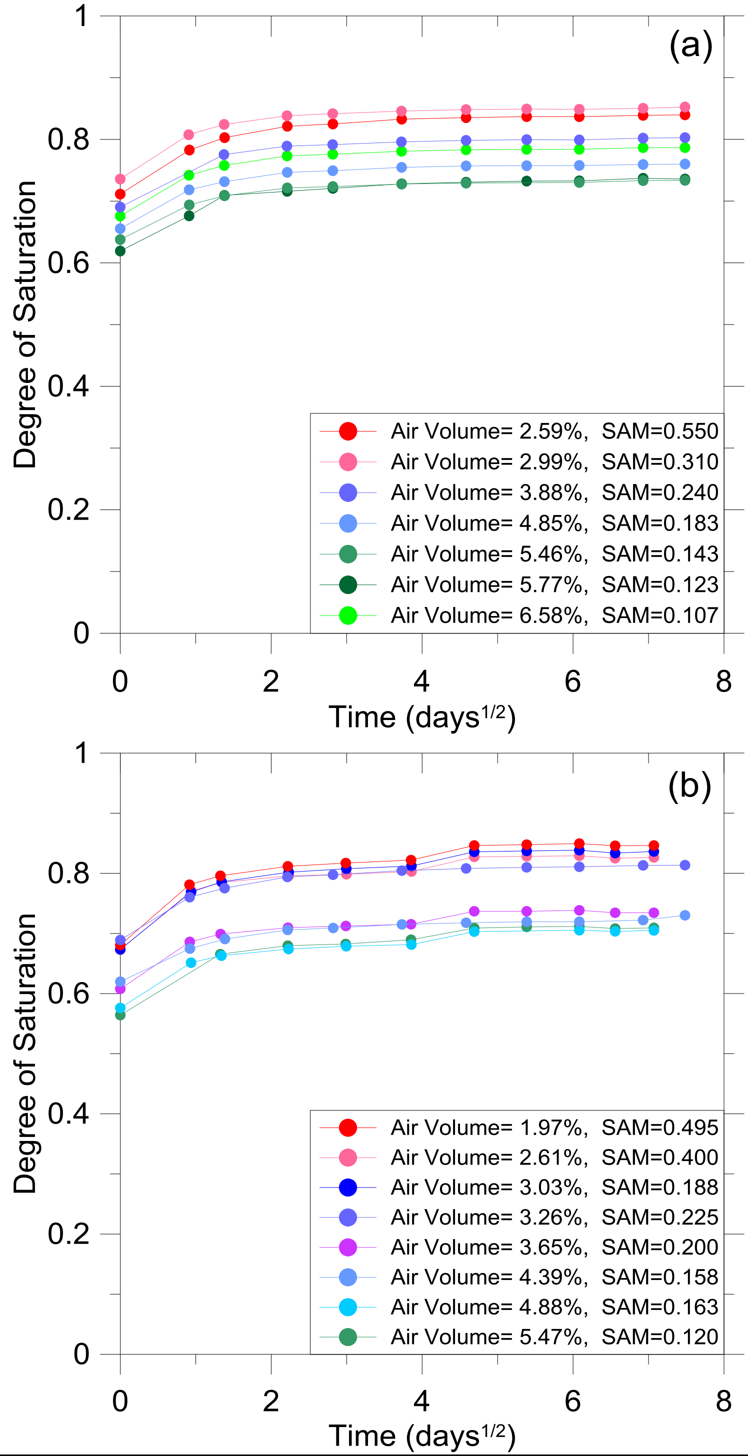


Figure 7 - Sample cutting, conditioning, and testing plan for each series of mixtures

(a) **(b)** **(c)**

Figure 8 - Current Testing States (a) Sorption samples conditioning at 50% relative humidity (b) Sample labeling convention cut and cored LGCC sample (c) LGCC Test Setup.


(a)
Degree of Saturation
Time (days$^{1/2}$)
Air Volume= 2.59%, SAM=0.550
Air Volume= 2.99%, SAM=0.310
Air Volume= 3.88%, SAM=0.240
Air Volume= 4.85%, SAM=0.183
Air Volume= 5.46%, SAM=0.143
Air Volume= 5.77%, SAM=0.123
Air Volume= 6.58%, SAM=0.107
(b)
Degree of Saturation
Time (days$^{1/2}$)
Air Volume= 1.97%, SAM=0.495
Air Volume= 2.61%, SAM=0.400
Air Volume= 3.03%, SAM=0.188
Air Volume= 3.26%, SAM=0.225
Air Volume= 3.65%, SAM=0.200
Air Volume= 4.39%, SAM=0.158
Air Volume= 4.88%, SAM=0.163
Air Volume= 5.47%, SAM=0.120

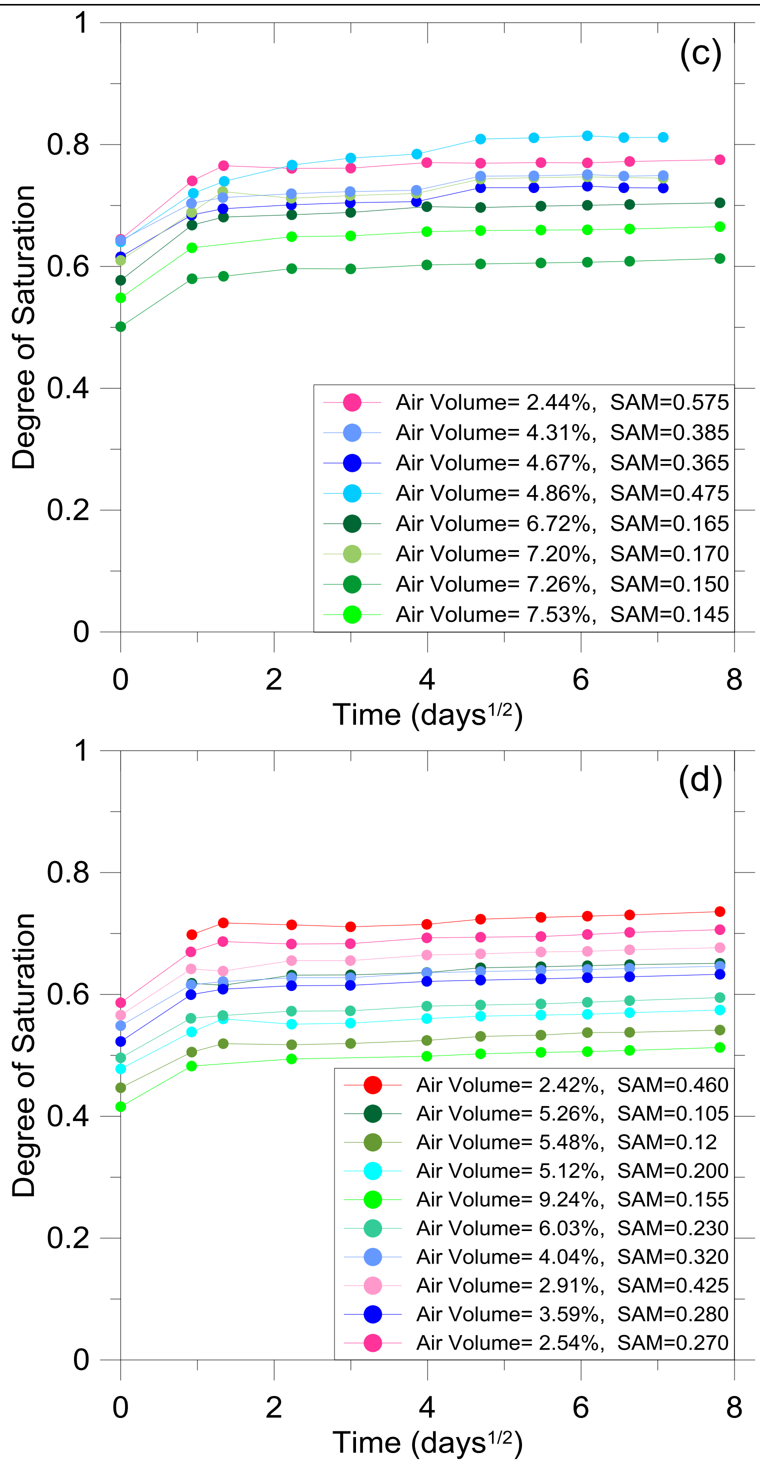
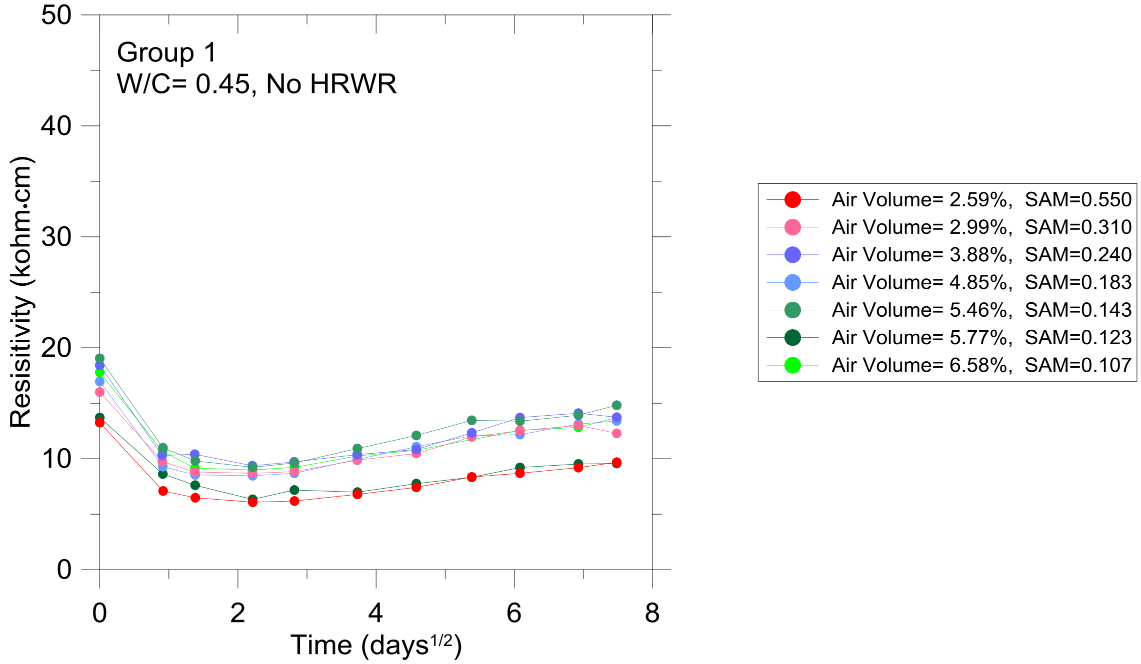
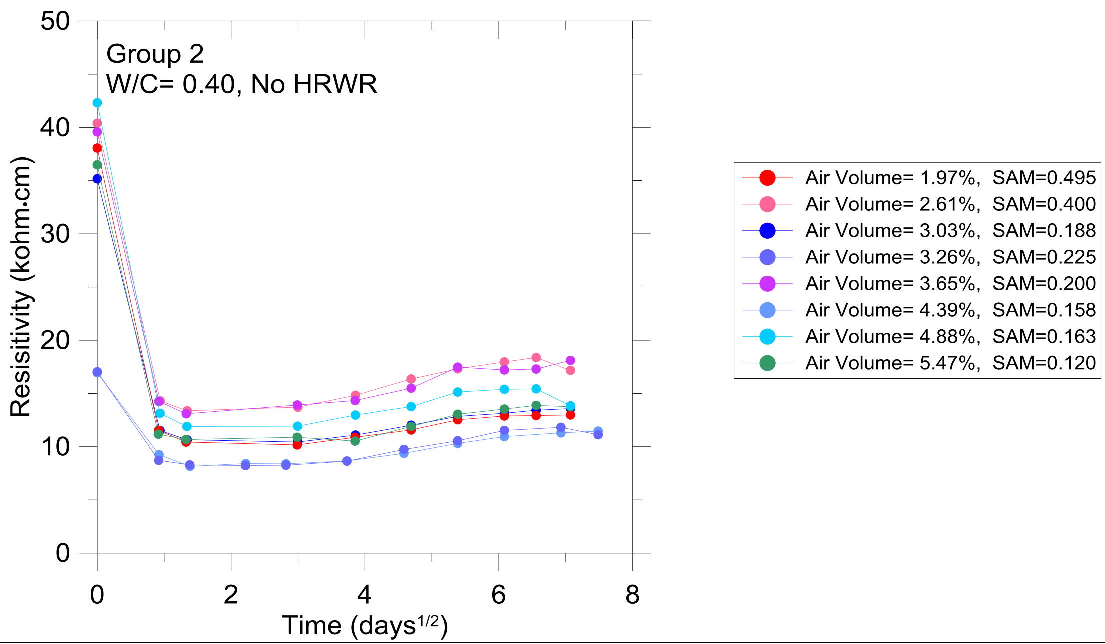


Figure 9 Degree of Saturation over Time for (a) Group 1, (b) Group 2, (c) Group 3 and (d) Group 4 Cylinders Submerged in Pore Solution



Group 1
W/C= 0.45, No HRWR
Resisitivity (kohm.cm)
Time (days^1/2)
Air Volume= 2.59%, SAM=0.550
Air Volume= 2.99%, SAM=0.310
Air Volume= 3.88%, SAM=0.240
Air Volume= 4.85%, SAM=0.183
Air Volume= 5.46%, SAM=0.143
Air Volume= 5.77%, SAM=0.123
Air Volume= 6.58%, SAM=0.107



Group 2
W/C= 0.40, No HRWR
Resisitivity (kohm.cm)
Time (days^1/2)
Air Volume= 1.97%, SAM=0.495
Air Volume= 2.61%, SAM=0.400
Air Volume= 3.03%, SAM=0.188
Air Volume= 3.26%, SAM=0.225
Air Volume= 3.65%, SAM=0.200
Air Volume= 4.39%, SAM=0.158
Air Volume= 4.88%, SAM=0.163
Air Volume= 5.47%, SAM=0.120

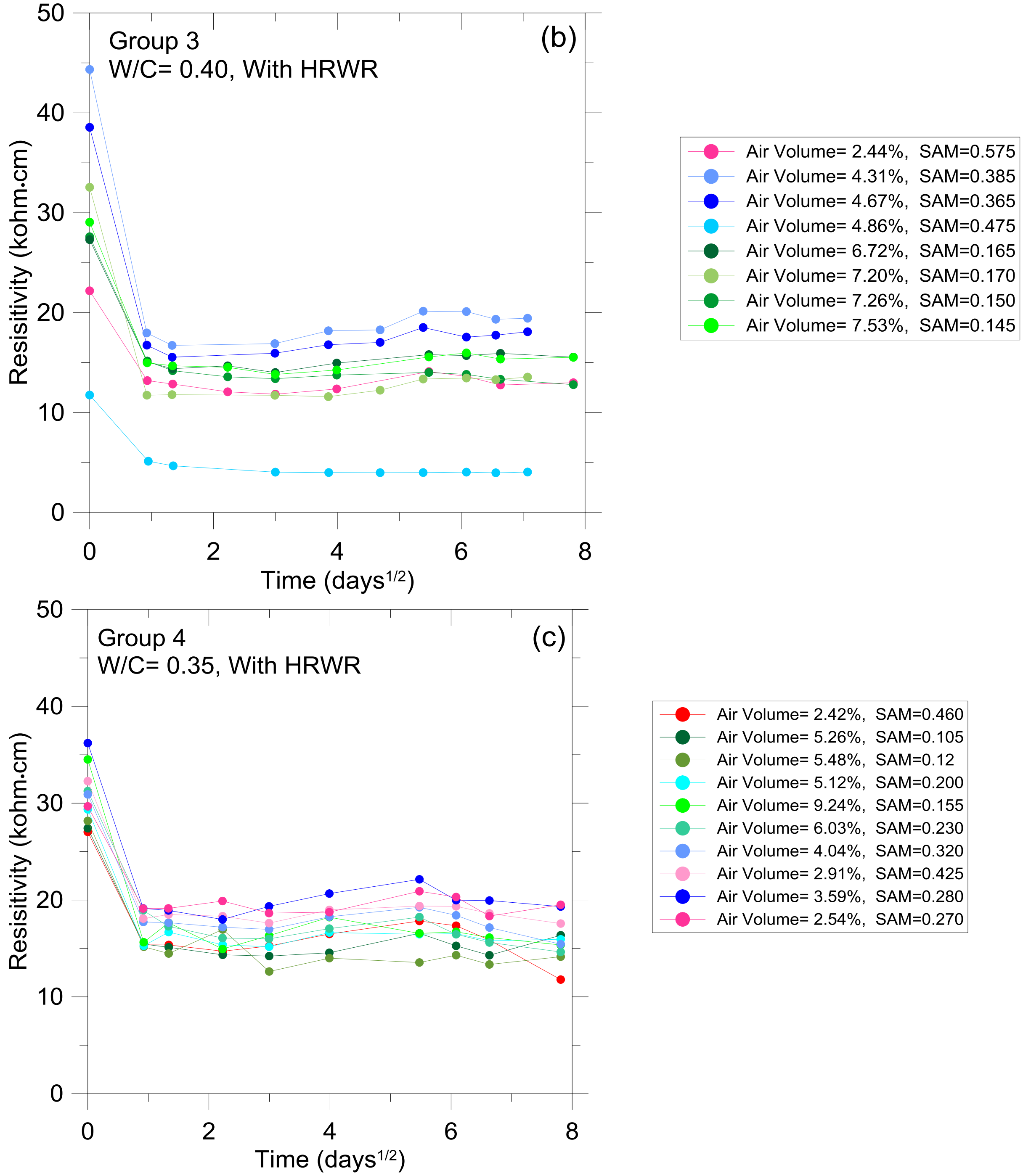
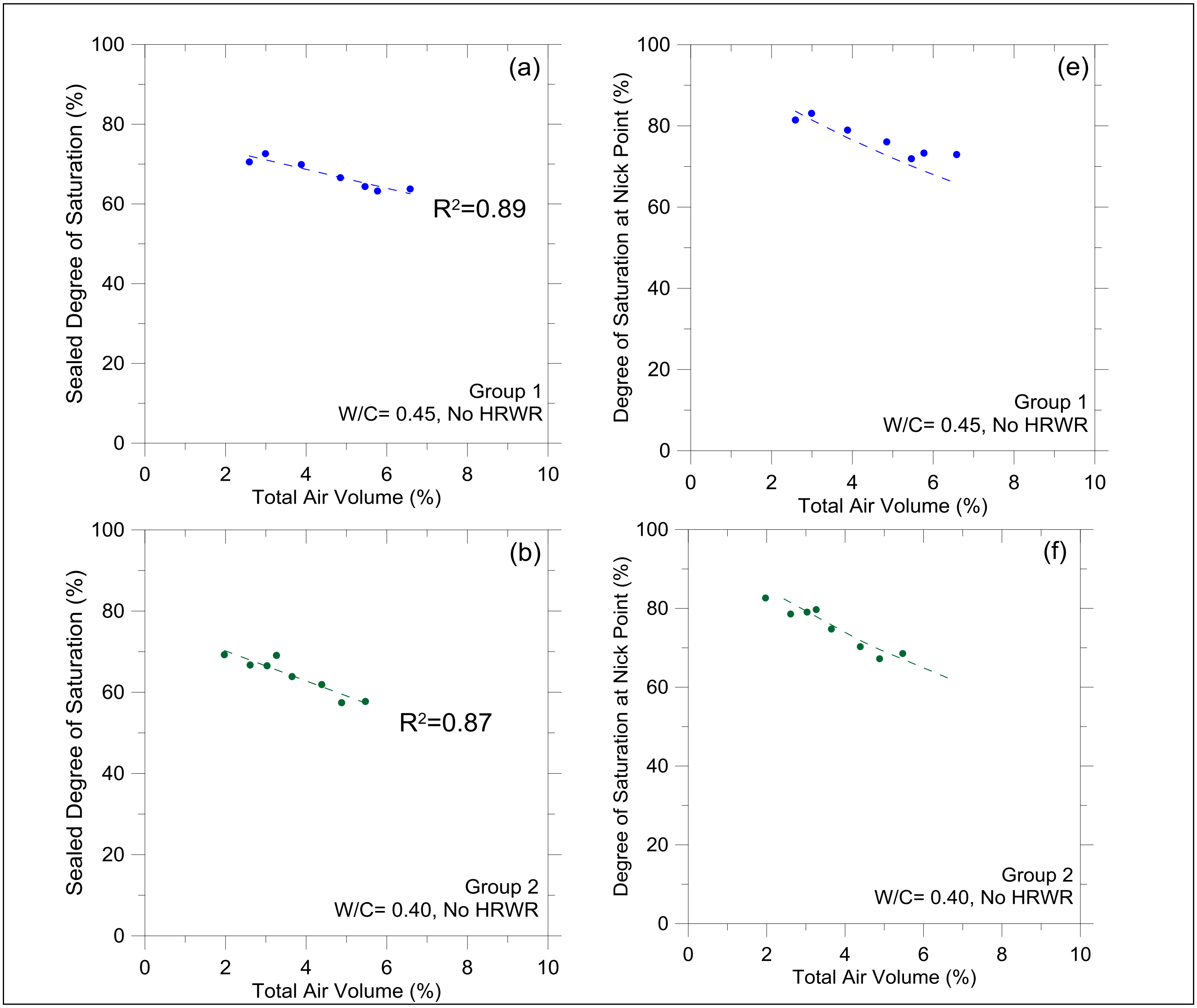


Figure 10 Sealed Resistivity and Submerged Resistivity for all 4 mixture groups



(a)
R^2=0.89
Group 1
W/C= 0.45, No HRWR
Sealed Degree of Saturation (%)
Total Air Volume (%)
(e)
Group 1
W/C= 0.45, No HRWR
Degree of Saturation at Nick Point (%)
Total Air Volume (%)
(b)
R^2=0.87
Group 2
W/C= 0.40, No HRWR
Sealed Degree of Saturation (%)
Total Air Volume (%)
(f)
Group 2
W/C= 0.40, No HRWR
Degree of Saturation at Nick Point (%)
Total Air Volume (%)

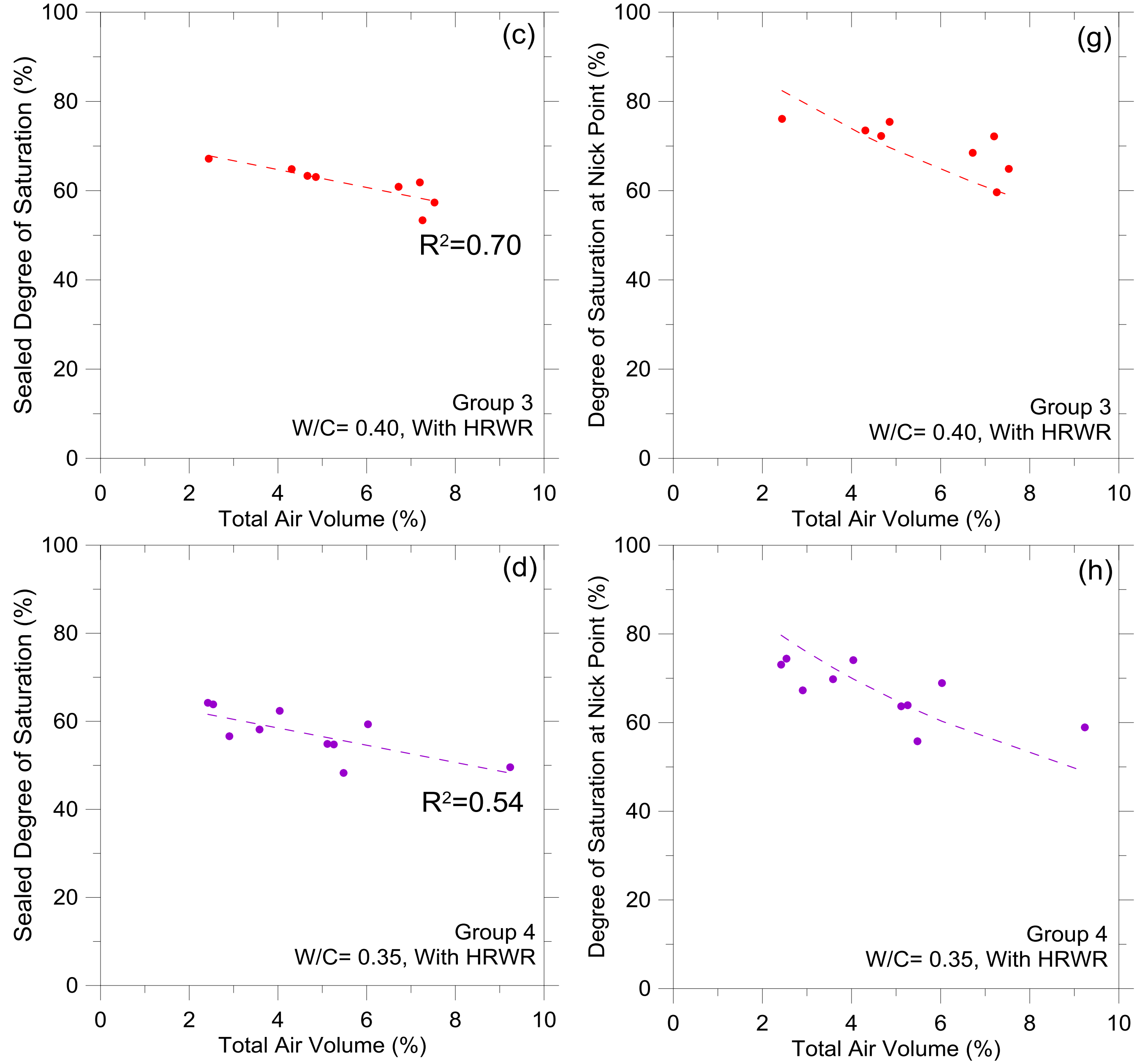
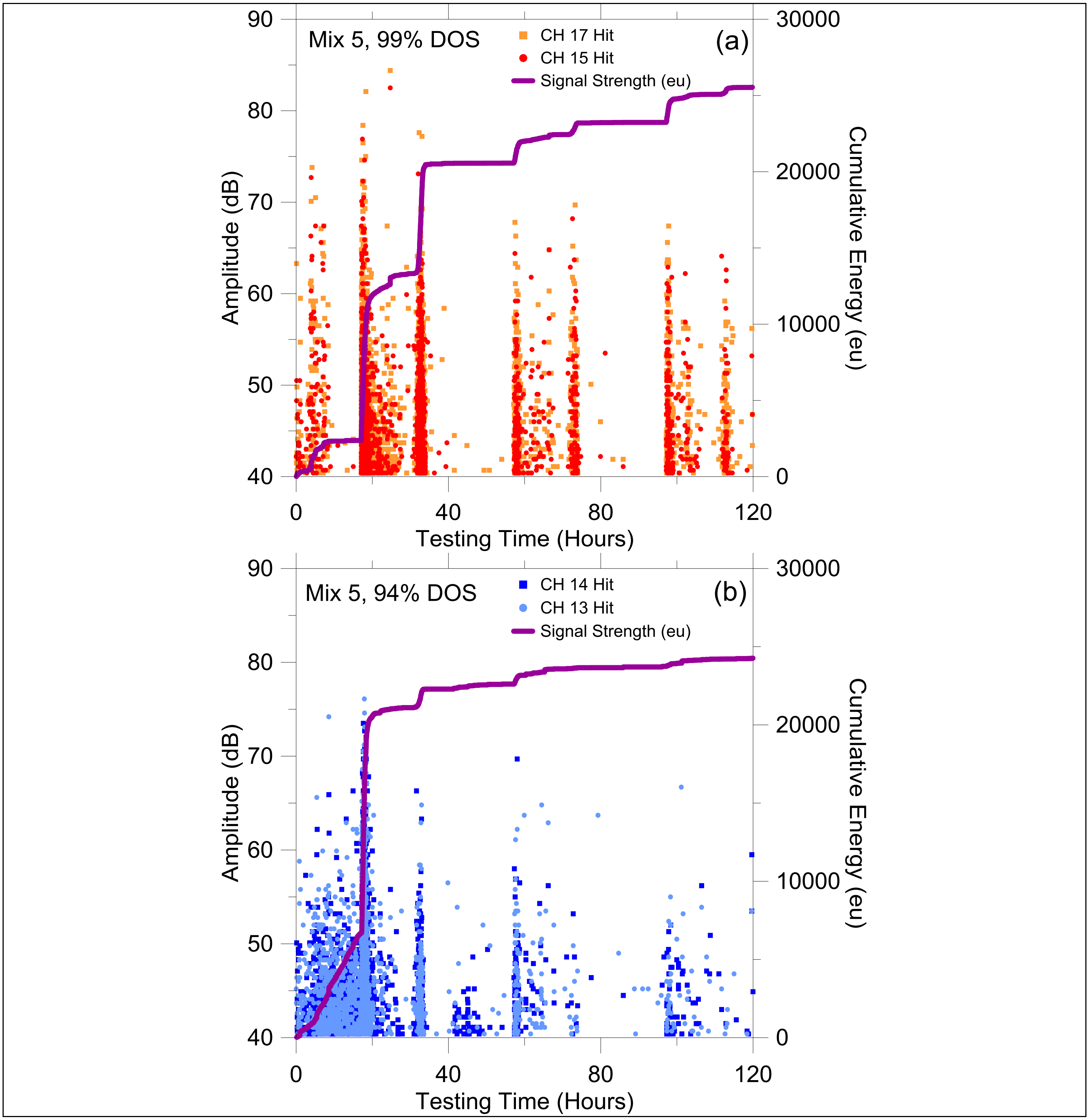


Figure 11 The Impact of Total Air Volume on (a-d) Sealed Degree of Saturation and (e-h) Nick Point Degree of Saturation Shown with Experimental Data and Theoretical Prediction



Mix 5, 99% DOS
CH 17 Hit
CH 15 Hit
Signal Strength (eu)
(a)
Amplitude (dB)
Cumulative Energy (eu)
Testing Time (Hours)
Mix 5, 94% DOS
CH 14 Hit
CH 13 Hit
Signal Strength (eu)
(b)
Amplitude (dB)
Cumulative Energy (eu)
Testing Time (Hours)

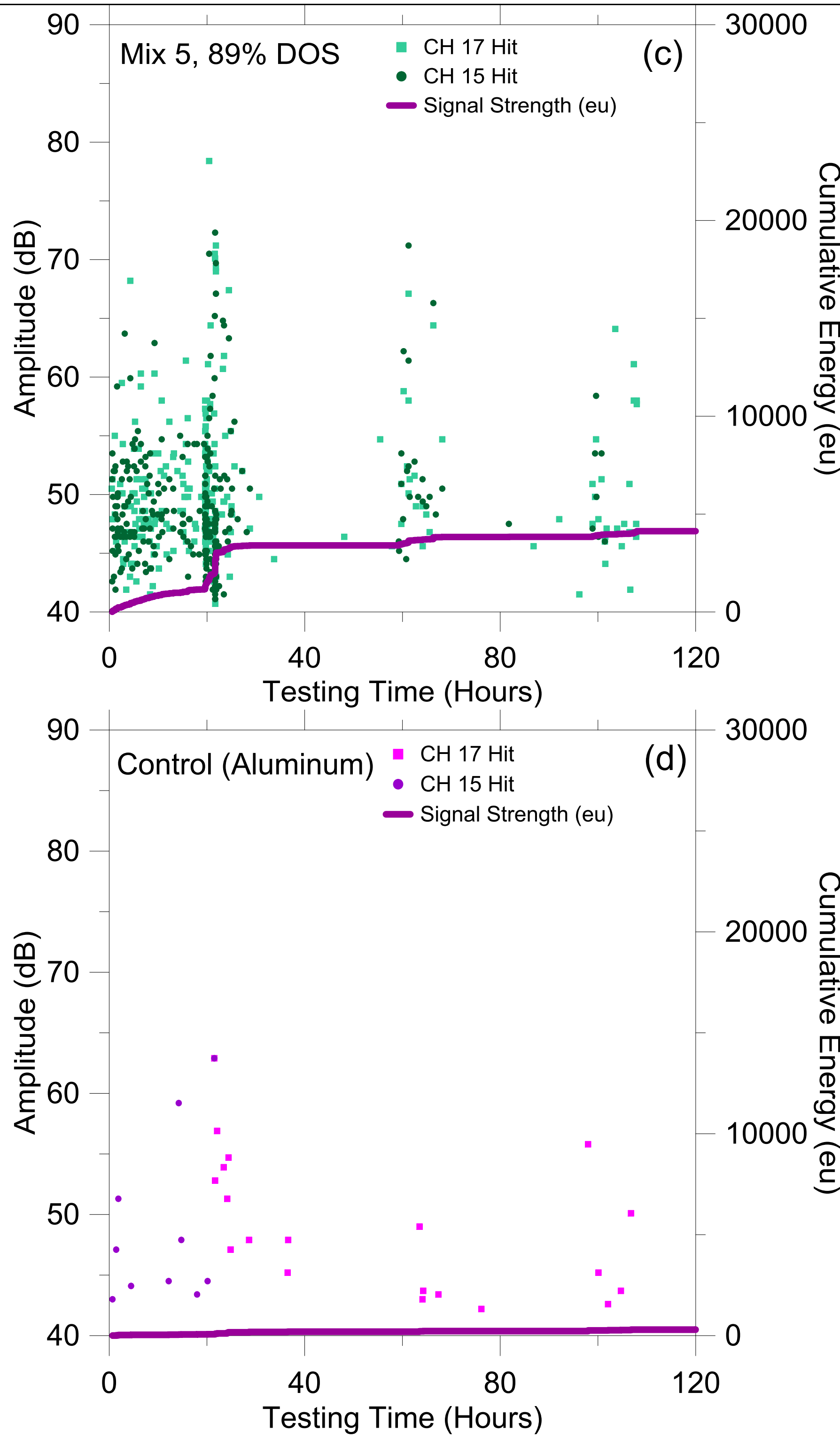
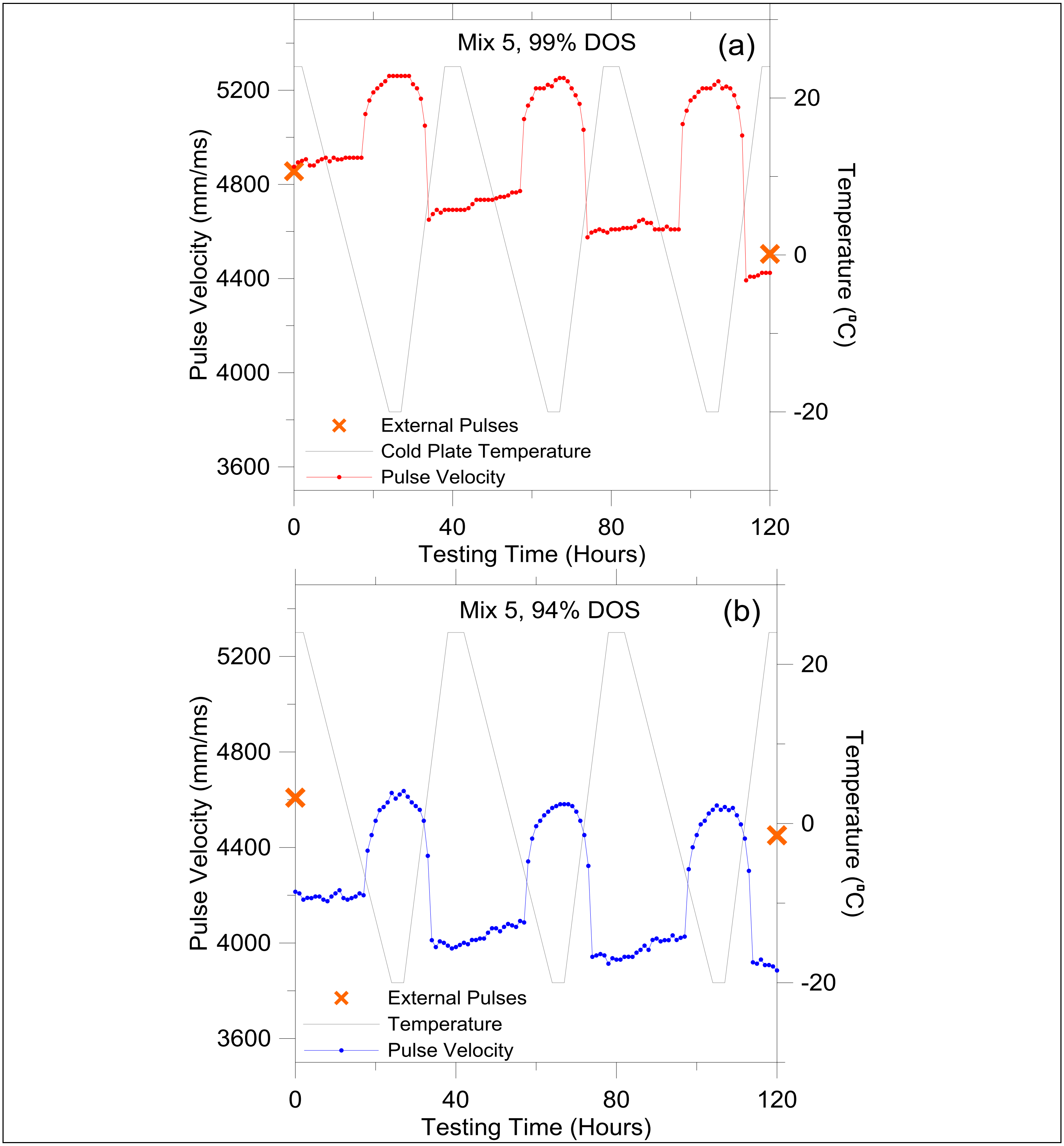


Figure 12 Acoustic Emission Hits and Cumulative Signal Strength (1eu=1nV·s) for (a) Fully Saturated (b) 94% Saturated and (c) 89% Saturated Concrete Undergoing Three Freeze-Thaw Cycles Compared to (D) an Aluminum Sample with No Freeze-Thaw Related Damage



Mix 5, 99% DOS
(a)
Pulse Velocity (mm/ms)
Temperature (°C)
Testing Time (Hours)
5200
4800
4400
4000
3600
20
0
-20
0
40
80
120
External Pulses
Cold Plate Temperature
Pulse Velocity
Mix 5, 94% DOS
(b)
Pulse Velocity (mm/ms)
Temperature (°C)
Testing Time (Hours)
5200
4800
4400
4000
3600
20
0
-20
0
40
80
120
External Pulses
Temperature
Pulse Velocity

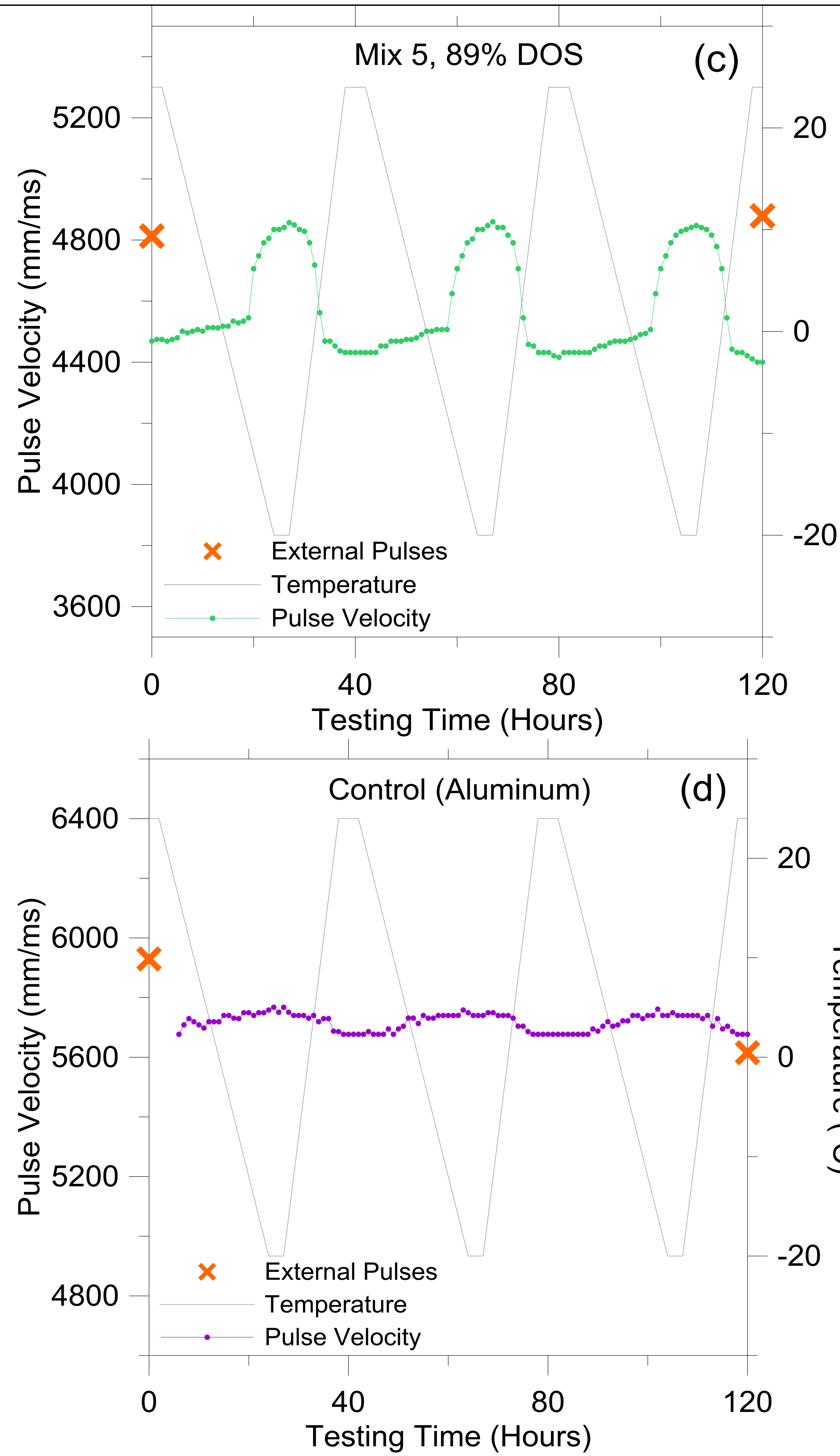


Figure 13 Wave Velocity Throughout Three Thermal Cycles for (a-c) Concrete Saturated to Three Different Degrees of Saturation Compared to (d) Control Aluminum Sample.

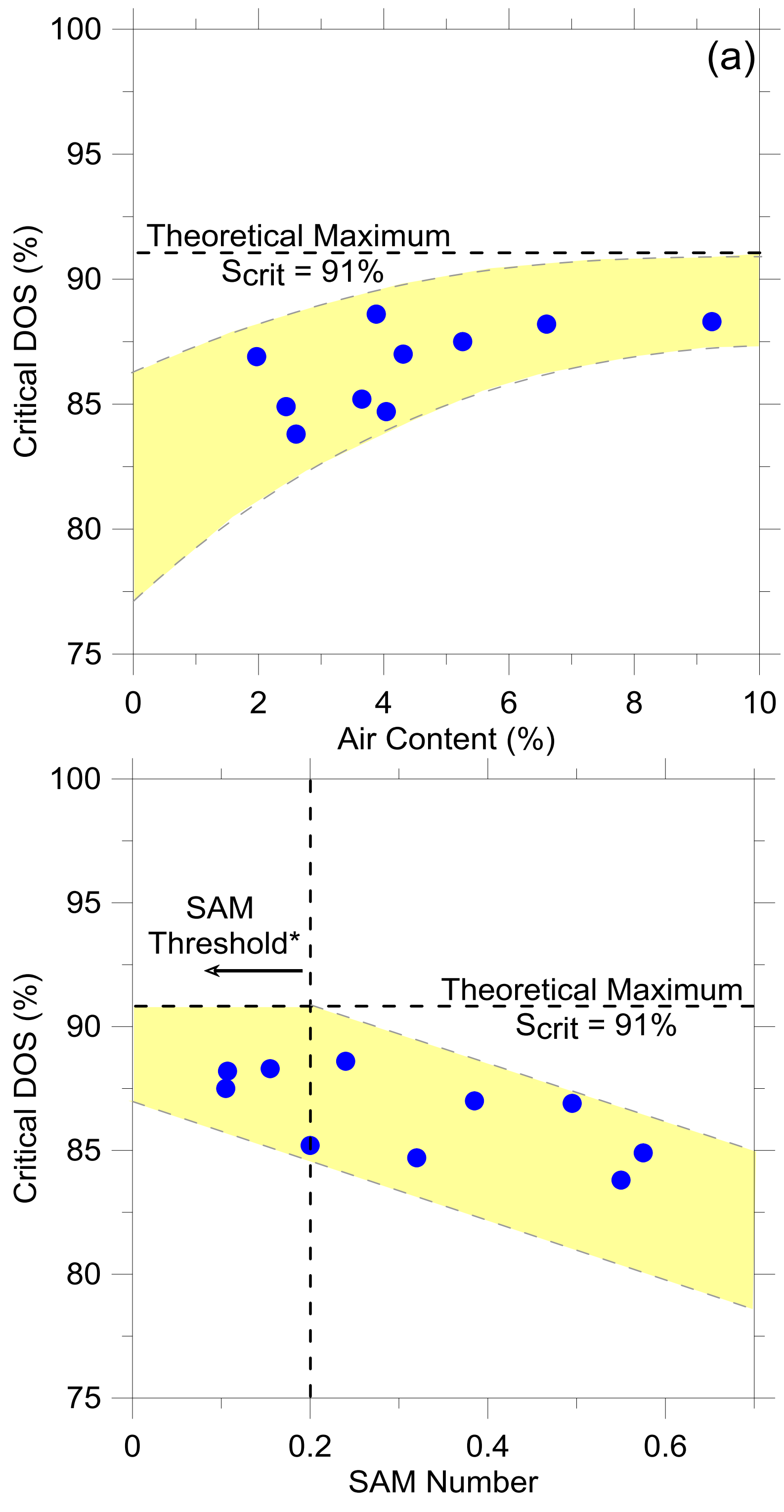


Figure 14 Projected Critical Degree of Saturation for Concrete Mixtures with a) Total Air Content and b) Air Quality (SAM Number) Using the Damage Index Following Three Freeze-Thaw Cycles

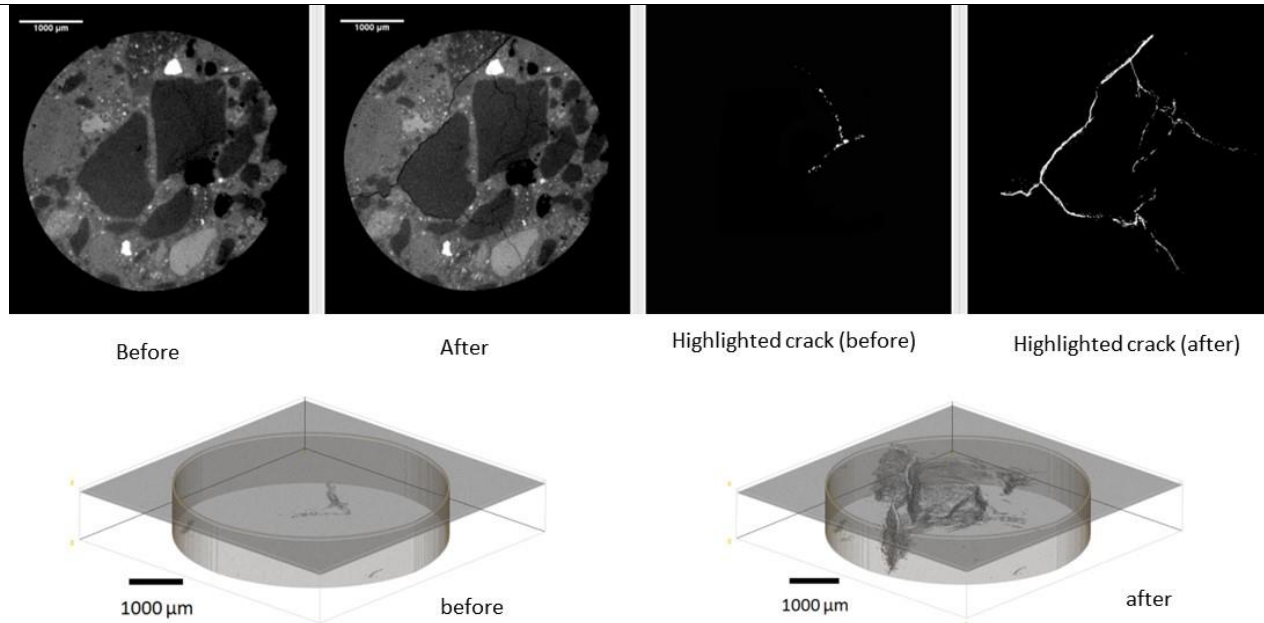


Figure 15 **–** An air entrained mortar sample shown both before and after a freeze thaw cycle. The highlighted cracks are shown from the cross sections. In addition, 3D data sets are shown of the crack distribution both before and after the freeze thaw cycle. The data was obtained with X-ray mCT.

Anticipated work next quarter:

The teams will continue preparing concrete mixtures to be investigated with the SAM and processing the materials produced previously. The ASTM C 457 sample preparation of the field samples will be completed for the samples provided other states.

The team also plans to begin examining the rate of the absorption and desorption, rate of damage, and degree of saturation on the damage with the concrete produced.

Work will continue with the mCT and neutron work.

Significant Results:

The data from over 300 different laboratory and field mixtures completed by two different labs suggest that a SAM number of 0.20 can correctly determine if the spacing factor is above or below 0.008" about 93% of the time. There is also over 80% agreement between the SAM results and the ASTM C666 results. Validation data has been gathered by FH Turner Fairbanks laboratory and the Pennsylvania DOT.

A presentation on the progress of the project was given at the NCC meeting in Omaha, NE and Miwaukee, WI. In addition the research team has shared information in two conference calls with the research oversight committee.

In addition, webinars and in person presentations have been given by Dr. Ley to the ACPA and their members, Missouri Science and Technology, North Dakota ACPA, Kansas KAPA, Utah ACPA, Iowa Paving conference, Colorado ACPA, Wisconsin ACPA, New Mexico Concrete School, Minnesota Concrete Association, Michigan DOT, The National ACPA Meeting, AASHTO SOM, and two National ACI conferences. The FHWA Mobile Concrete Lab visited the OSU campus for several days to discuss about our progress with the SAM and other testing methods.

The SAM is now being used in 33 states, two Canadian provinces, and in England. It has also been specified in two states Kansas DOT has developed a specification that they are starting to implement this summer.

The publication of the AASHTO TP118 test method is also an important result.

Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

There was some delay getting the contracts signed. This has delayed the start of the project some but the research team i doing their best to make up for this. The project is about four months behind schedule. A contract extension will likely be necessary.

Other than this issue the project is on time and on scope.

Potential Implementation:

The Provisional AASHTO test method for the Super Air Meter is in press. Changes to other test methods are also being discussed. Work will continue on the project to develop the precision and bias statement.

One paper has been submitted to a conference and several more are being authored to submit soon. Much of this work has been included as supplementary documents to previous quarterly reports.