Demonstration Project for Implementation of Performance Engineered Mixtures (PEM)

Final Report
for
MLR-19-01

October 2019
Construction & Materials Bureau

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16. Abstract

Concrete has traditionally been accepted by testing air, slump, and strength. However, these test methods usually do not have a direct relationship with long term durability. A number of new test methods have been developed that give a better prediction of long-term performance.

On a recent paving project on US 20 in Woodbury County, Iowa, several of the new test methods were evaluated to gain experience with the test methods and determine viability of using test methods for quality control and acceptance. The contractor performed quality control (QC) shadow testing using the SAM air meter test for air and freeze thaw potential, box test for workability, and resistivity testing for fluid transport properties. The Federal Highway Administration (FHWA) Mobile Concrete Laboratory was also on the project collecting data for the PEM pooled fund project.

Results indicated the new test methods are repeatable and provide valuable information on long term performance potential for concrete pavements.

17. Key Words	**18. Distribution Statement**
PEM, performance engineered mixtures, SAM Number, resistivity, concrete pavement, calcium oxychloride potential, AASHTO PP-84	No restrictions.

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Demonstration Project for Implementation of Performance Engineered Mixtures (PEM)

INTRODUCTION

The Iowa Department of Transportation applied for funds through the Performance Engineered Concrete Paving Mixtures pooled fund project (TPF-5(368)) to collect data and demonstrate the new tests. The FHWA approved the application for the full $100,000 with a 20% match for a total of $80,000. Application can be found in the Appendix.

The project location was on U.S. 20 in Woodbury County between Correctionville and Holstein. Ames Construction Inc. was awarded the $62.9 million contract for this stretch of U.S. 20, which is divided into 6 construction segments. Cedar Valley Corporation, LLC is the paving subcontractor responsible for the U.S. 20 paving. Grading and paving began in 2016 and was completed in 2018. All of the sampling and testing was performed in segment 4 westbound, roughly 11 miles within the U.S. 20 corridor between Holstein and Correctionville, Iowa. Figure 1 shows the project location.

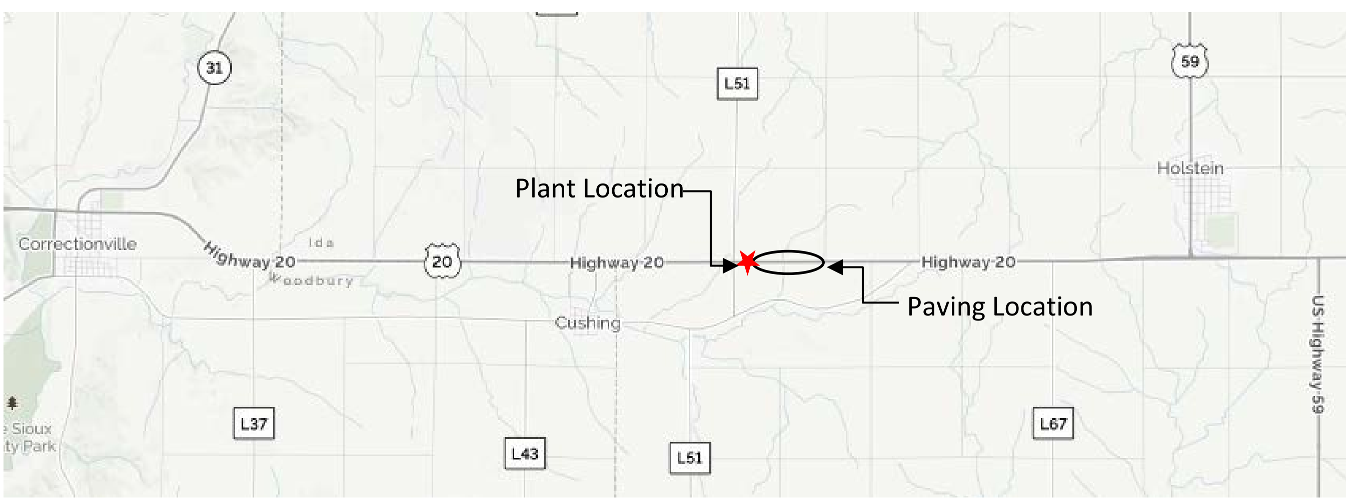

Figure 1: U.S. 20 Project Location

In segment 4, two additional lanes are being constructed to the north side of existing U.S. 20 westbound. The pavement surface of the additional mainline is 26' separated into a 12' inside lane and a 14'outside lane with a 4' inside and 6' outside shoulders. New mainline pavement is a 10 inches of PCC concrete over a 6 inch granular subbase. The U.S. 20 new mainline cross section is shown in Figure 2.

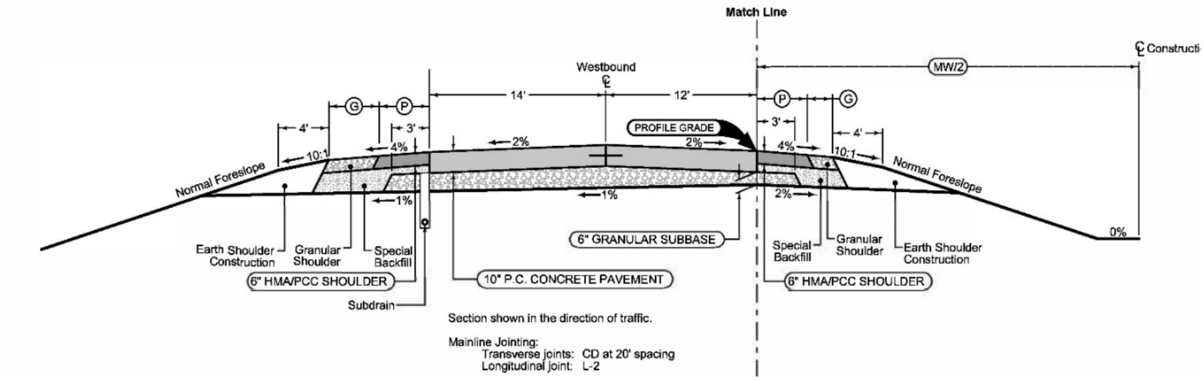

Figure 2. U.S. 20 Cross Section

PEM implementation funds were used for the following:

- Incorporate the SAM, box test, VKelly, unit weight, bucket test, resistivity, and calcium oxychloride potential testing into the mix design/approval process.
- The Iowa DOT coordinated with the CP Tech Center to obtain project materials and developed a mix design for the contractor's Class A mix used on the shoulder. Once the lab mix parameters were established, the contractor did a field trial batch to include SAM testing and either Box Test to validate the lab mix. While the FHWA trailer was on the project, the Class A PEM modified mix was used to compare with the contractor designed mix (QMC) they were currently using. The contractor performed SAM testing, box test, and resistivity testing (formation factor).
- The contractor provided an extra technician to perform additional sampling and testing for the remainder of QMC paving and 1 week of Modified PEM A mix. These tests were performed as shadow tests only:
    - Plastic air test and SAM test side by side comparison on QC air tests
    - Plastic air and SAM test behind paver twice per week
    - Temperature and unit weight twice per day
    - One box test per day
    - Cast one cylinder per day. The air content, SAM number, unit weight and temperature was recorded on the cylinder mold after casting. Cylinders were sent to Central Laboratory for resistivity testing after initial testing by the contractor and for hardened air analysis. Since the Iowa DOT's RapidAir457 equipment needed repairs, the hardened air analysis was performed by Oklahoma State University and Tyler Ley.
    - Resistivity testing was performed on concrete cylinders per AASHTO T358 at ages of 7, 14, 28, 56, and 90 days. One set of cylinders were tested for calculation of the ionic penetration (formation factor) of the concrete was completed per Appendix X2 of AASHTO PP 84-17.
    - Calcium oxychloride potential was performed by the CP Tech Center. At time of this report, the LT-DSC was being repaired, so results were not available.
    - VKelly testing was performed by the CP Tech Center.
- The contractor performed QC testing using each of these methods and submitted these results to Iowa DOT. The contractor updated U.S. 20 quality control plan to include SAM meter testing, box test, and formation factor, including corrective action were added to the QC plan. In addition, the contractor included QC procedures for percent within limits (PWL) plastic air content (shadow testing only).
- The Iowa DOT already requires control charts to plot aggregate combined gradations, air content before and after paver, unit weight, moistures, and w/c ratio. The Iowa DOT added control charts for the SAM air test, SAM number, box test, and resistivity testing for this segment of the

U.S. 20 project. The contractor also monitored PWL for plastic air specification compliance (shadow testing only).

MIX DESIGN CHARACTERISTICS

The contractors mix design was used for the PEM testing. The Iowa DOT quality management concrete (QMC) mix design requires a well graded mix in Zone II of Shilstone coarseness/workability chart. The mix is designed for 6% air content, a basic w/c ratio of 0.40 and MOR-TPL of 640 psi at 28 days. Contractors are required to perform quality control testing of QMC mixes also. Tables 1 summarize the mixture design proportions, for segment 4 of the U.S. 20. For all mixes, the air entraining agent was Brett Admixture Eucon AEA92 and water reducer was Brett Admixture Eucon WR 91.

Using the mixture proportions from the mixture design, the volume of paste was calculated for this mixture. The paste volume for this mixture was 24.4%. To limit shrinkage and take advantage of other benefits such as lower cement/cementious contents, lower cost etc., it is recommended to have paste volume of less than 25%.

Table 1: Mixture Design Proportions

Material	Description/Source	Weight
Cement Type I/II	GCC, Pueblo PC2902	449 lb.
Fly Ash	HW Class C, Nebraska City	112 lb.
Coarse Aggregate	1” x #4 – A18528LG Everist Crocker	1382 lb.
Intermediate Aggregate	3/8” – A47504 LG Everist Larrabee	378 lb.
Fine Aggregate	Sand – A18514 LG Everist - Washta	1361 lb.
Water	Municipal	224 lb.

Figure 3 shows the combined aggregate grading on the Shilstone coarseness and workability factor graph. The workability & coarseness factor graph of the combined aggregate gradation fell in the optimal or well graded region.

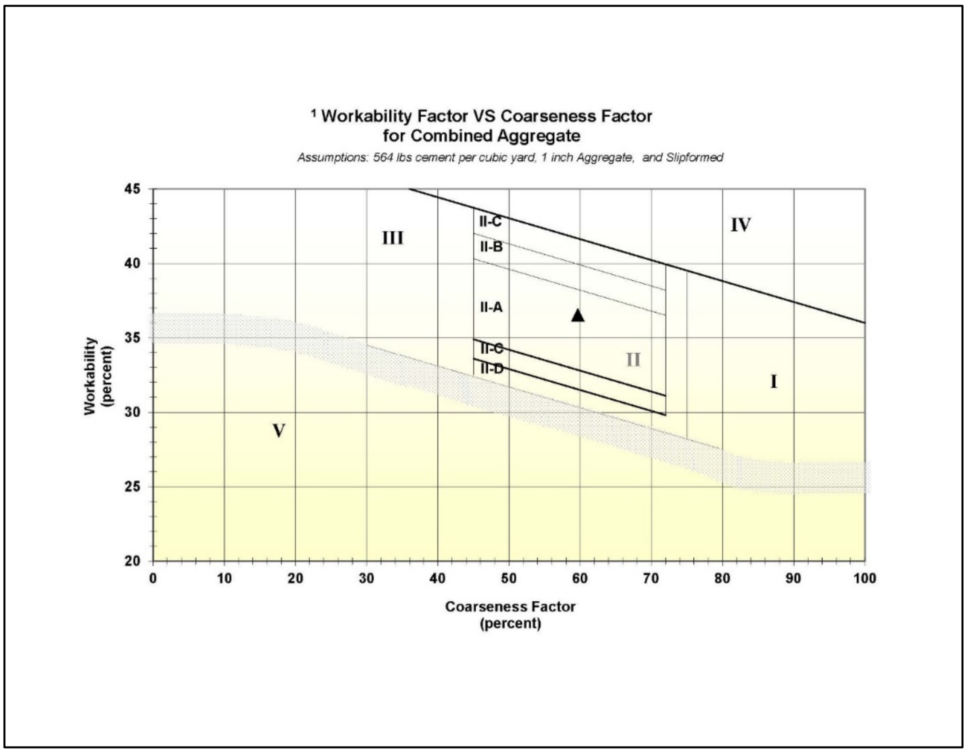

Figure 3: Coarseness Factor Chart

Figure 4: Cedar Valley Paving on US 20

PEM Mix

A reduced cement content mix was utilized on the shoulders. The CP Tech Center used the contractor's aggregate proportions and developed a cement content based on dry rodded unit weight for the combined grading. The original Class A shoulder mix was 550 pounds per cubic yard with a coarse and fine aggregate. The modified PEM mix was 515 pounds per cubic yard with coarse, intermediate and fine aggregates. Below are the comparisons between the Class A and PEM mix designs.

A Mix	**Abs. Vol.**	**lbs/CY**
CEMENT:	0.083	440
FLY ASH:	0.025	110
WATER: w/c=0.474	0.155	261
FINE AGGREGATE (45%):	0.305	1357
COARSE AGGREGATE (55%):	0.372	1680
INTERMEDIATE AGG.:	0	0
AIR:	0.06	0
Paste Content, %	26.3	

PEM Mix	**Abs. Vol.**	**lbs/CY**
CEMENT:	0.078	412
FLY ASH:	0.024	103
WATER: w/c=0.40	0.122	206
FINE AGGREGATE (44%):	0.315	1401
COARSE AGGREGATE (44%):	0.315	1422
INTERMEDIATE AGG. (12%):	0.086	387
AIR:	0.06	0
Paste Content, %	22.4	

The contractor expressed concerns with lowering the cement content, noting the Class A mix sometimes is lean. They utilized the PEM mix on the shoulders with the caveat that if they had issues with workability, they would add 10 pounds per cubic yard until they achieved the workability they desired.

Prior to paving, the contractor performed a trial batch of the PEM mix. The box test indicated the mix would be workable.

Figure 5: Box Test PEM Shoulder Mix

The contractor decided to go ahead with the PEM mix and do a trial placement on the shoulders. The contractor was pleasantly surprised how well the PEM mix placed. They would have liked to have tried it on the mainline, if they had any paving left.

Figure 6: Paving with PEM Shoulder Mix

TEST RESULTS

All test data may be found in the Appendix.

SAM Testing – SAM number testing was performed once per day. As recommended by Tyler Ley, action limits were placed on the control charting with 0.20 or lower within limits, 0.25 as a warning limit, and 0.30 as a rejection limit. Of the 36 tests performed, all SAM number test results were at or below the rejection limit of 0.30.

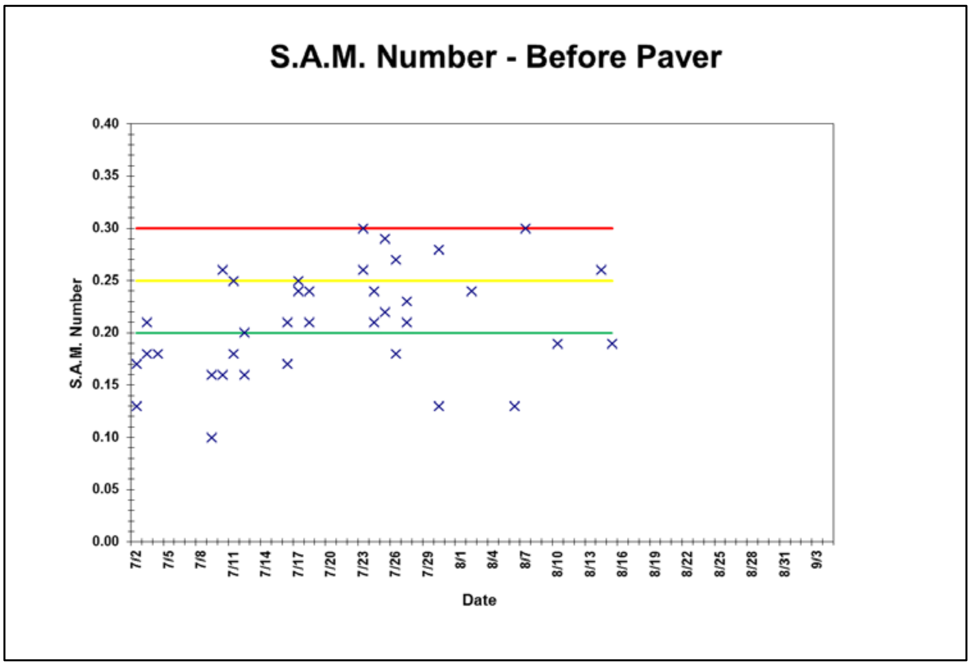

Figure 7: SAM Test Data

For their own information, the contractor also ran side by side comparison of plastic air content between the SAM meter and a standard air meter. Of the 36 tests comparisons, five test results were outside of the Iowa DOT limit of ±0.4%.

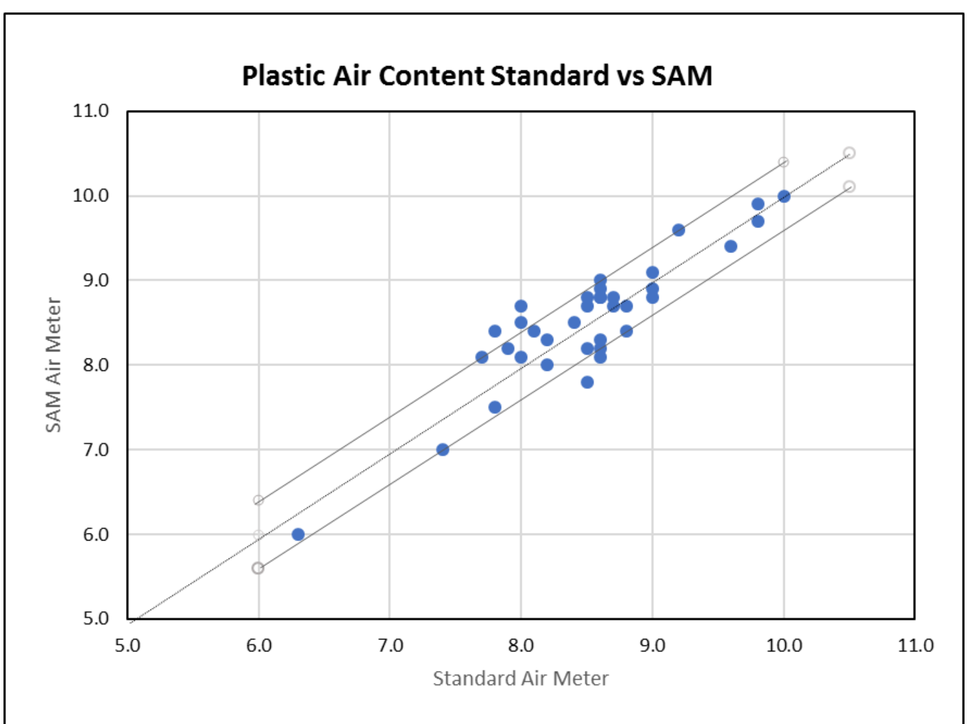

Figure 8: SAM Air vs Standard Air

Box Test - The box test was tested once per day during production. All but three tests were either a 1 or 2. Although, the three tests were at a 3 rating, there were no issues with workability. Since the test requires judgement comparing against images, these results may have been between a 2 or 3 rating.

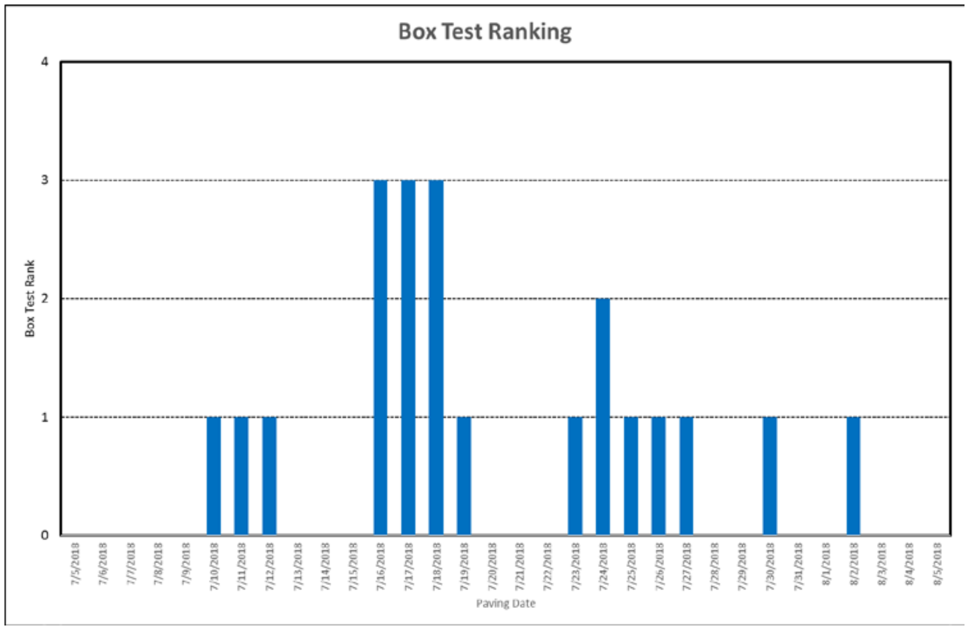

Figure 9: Box Test Results

Resistivity and Formation Factor – Cylinders were cast every day and placed in a 5-gallon bucket with a well-sealed lid, with 3.5 gallons of water and 102.6g NaOH, 143.90g KOH and 27g $Ca(OH)_2$ into. Resistivity testing was performed by the contractor at 3 and 7 days. The buckets were delivered to the Central Laboratory, placed in the moist room, and resistivity was performed at 14, 28, 56, and 91 days. Results are shown in Figure 10.

One set of two cylinders tested following the protocol found in the Appendix for the formation factor (F). The resistivity after 91 days was 21.1 and 19.9 k-ohm cm respectively, with correlates with formation factors (F) of 2111 and 1999. These values are classified as low to very low. Since test methods were being finalized during this project, temperature correction was not included in the resistivity results.

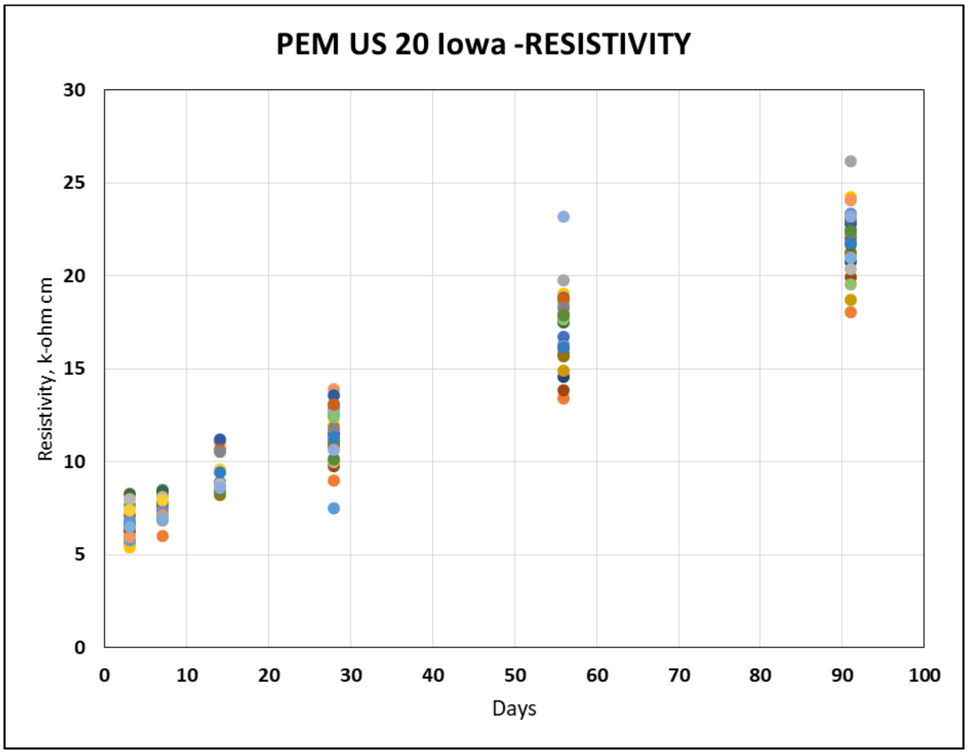

Figure 10: Resistivity Test Results

Air Content PWL – Since quality control charts are normally required on Iowa DOT QMC paving projects, the contractor was encouraged to try new quality control techniques. The contractor chose to try percent within limits of plastic air content to learn about more. Table 2 shows the percent within limits of the plastic air content.

Table 2: Air PWL Results

US 20 Iowa Plastic Air Content - Percent Within Limits											
Lot #	Sum	Count	Lot Average	Std Dev	Lower	Upper	QL	QU	PWLL	PWLU	n=8 PWL
1	90.2	10	9.020	0.654557	6	10	4.61381	1.497197	100	94	94
2	111.1	13	8.546	0.550175	6	10	4.6279	2.642517	100	100	100
3	40.4	5	8.080	0.178885	6	10	11.62755	10.73313	100	100	100
4	93.1	11	8.464	0.578399	6	10	4.259406	2.656235	100	100	100
5	74.6	9	8.289	0.431406	6	10	5.30565	3.966359	100	100	100
6	99.7	12	8.308	0.635979	6	10	3.629573	2.65994	100	100	100
7	88.3	11	8.027	0.812516	6	10	2.495057	2.427925	100	100	100
8	97.8	12	8.150	0.77401	6	10	2.777743	2.390151	100	100	100
9	89.9	11	8.173	0.397721	6	10	5.462946	4.594361	100	100	100
10	94.1	11	8.555	0.533598	6	10	4.787393	2.708881	100	100	100
11	88.7	10	8.870	0.537587	6	10	5.338669	2.101985	100	99	99
12	27.3	3	9.100	0.360555	6	10	8.597853	2.496151	100	100	100
13	77.7	9	8.633	0.845577	6	10	3.114245	1.616254	100	96	96
14	106.5	13	8.192	0.537683	6	10	4.077327	3.362006	100	100	100
15	108.4	13	8.338	0.833205	6	10	2.806586	1.994153	100	99	99
16	98.9	12	8.242	0.22747	6	10	9.854796	7.72997	100	100	100
17	77.1	9	8.567	0.678233	6	10	3.784344	2.113335	100	99	99
18	76.1	9	8.456	0.563718	6	10	4.356001	2.739747	100	100	100
19	90.9	11	8.264	0.680107	6	10	3.328354	2.553074	100	100	100
20	34.4	4	8.600	1.051982	6	10	2.471525	1.330821	100	91	91
21	51.1	6	8.517	1.032311	6	10	2.437895	1.436905	100	93	93
22	43.8	5	8.760	0.95289	6	10	2.896451	1.301304	100	91	91

Combined grading – On QMC paving projects, the Iowa DOT requires well graded aggregate combinations in Zone II using the Shilstone chart. The coarseness and workability factor weekly averages are shown in Figure 11.

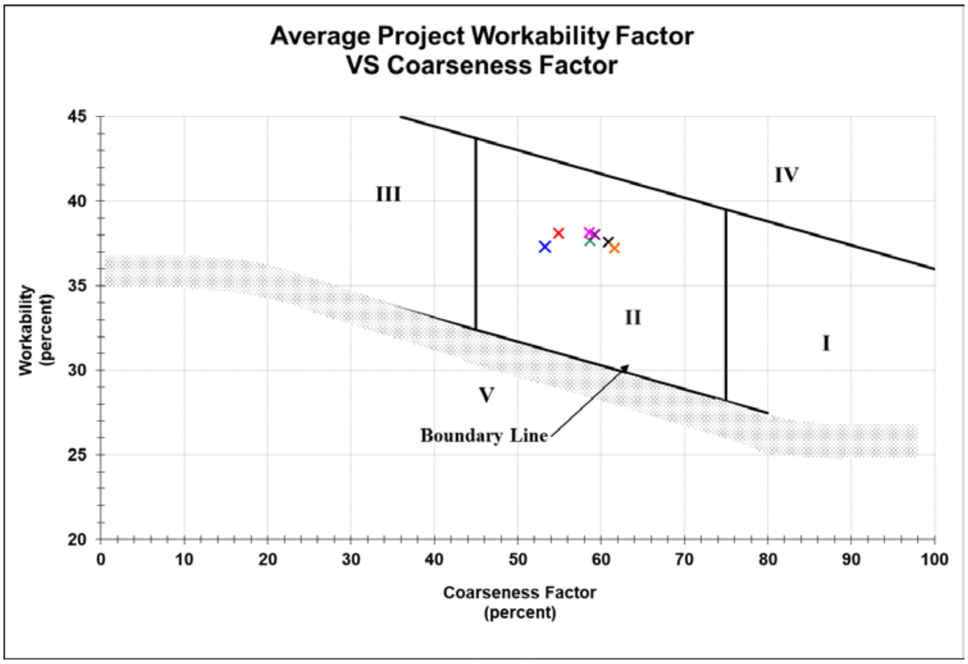

Figure 11: Weekly Averages Shilstone Coarseness/Workability Factors

The combined grading was also plotted on the tarantula curve to see how closely it would fit. Although the proportions were developed with Shilstone principles, the combined grading also fit the tarantula curve. Figure 12.

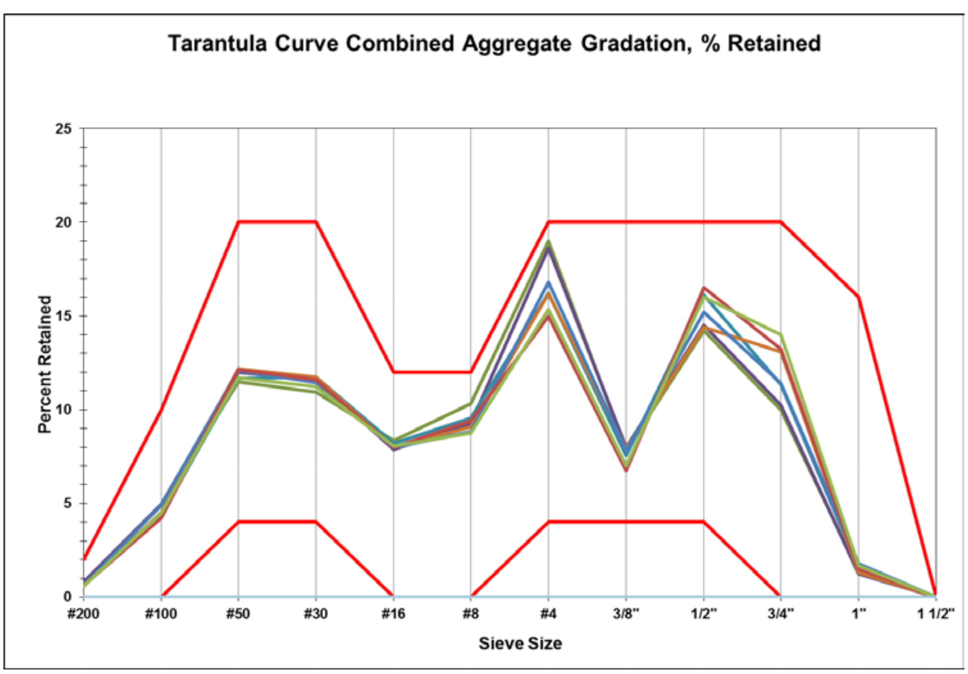

Figure 12: Weekly Averages Tarantula Curve Combined Grading

Hardened Air Analysis

After the cylinders were tested for resistivity, a hardened air void analysis was performed using the RapidAir457 equipment. Testing was performed at Oklahoma State University. Air data can be found in Table 3. SAM Number versus spacing factor is shown in Figure 12 and plastic versus hardened air in Figure 13. All other hardened air void parameters may be found in the Appendix.

Table 3: Plastic and Hardened Air Results

Iowa DOT PEM Project US 20 Woodbury Co.

Cylinder #	Date	UW (lbs/ft3)	Station	Plastic Air (%)	Sam Air (%)	Sam Number	Mix	Rapid Air457 Air (%)	Rapid Air457 S. F. (in.)
1	7/10/2018	140.56	11317+00	9.0	8.9	0.26	QMC	6.20	0.0065
2	7/11/2018	140.96	11305+00	8.6	8.3	0.25	QMC	8.94	0.0053
3	7/12/2018	140.96	11253+00	9.4	9.3	0.28	QMC	8.52	0.0047
4	7/16/2018	141.37	11232+00	7.7	8.1	0.21	QMC	7.61	0.0059
5	7/17/2018	141.37	11198+00	7.9	7.9	0.25	QMC	5.55	0.0061
6	7/18/2018	141.77	11160+00	9.0	8.8	0.24	QMC	7.12	0.0058
7	7/18/2018	141.37	11142+00	8.3	8.7	0.21	QMC	5.67	0.007
8	7/23/2018	141.77	11092+00	8.6	8.8	0.30	QMC	7.21	0.0057
9	7/24/2018	141.37	11057+00	8.6	8.1	0.21	QMC	5.85	0.0064
10	7/25/2018	140.96	11019+00	9.8	9.7	0.22	QMC	8.70	0.0048
11	7/26/2018	142.17	10976+00	8.5	8.8	0.18	QMC	7.01	0.0054
12	7/27/2018	141.37	10943+00	8.2	8.3	0.21	QMC	7.09	0.0058
13	7/30/2018	141.77	10874+00	8.6	8.9	0.28	QMC	7.15	0.0051
14	7/30/2018	141.37	Shoulder	6.2	6.1	0.32	A-2	5.99	0.0056
15	8/2/2018	142.17	Shoulder	7.0	6.9	0.24	A-2	5.49	0.0066
16	8/2/2018	142.57	TL	8.1	8.4	0.25	QMC	7.14	0.0068
17	8/6/2018	141.37	TL	8.4	8.5	0.13	QMC	7.74	0.005
18	8/6/2018	141.37	TL	8.4	8.5	0.13	QMC	4.34	0.0057
19	8/7/2018	142.17	TL	9.8	9.9	0.30	QMC	5.07	0.0064
20	8/8/2018	141.77	Shoulder	9.6	9.7	0.13	PEM	6.02	0.0062
21	8/8/2018	142.57	Shoulder	8.6	8.0	0.20	PEM	3.99	0.0067
22	8/9/2018	141.77	WE Gore	7.1	6.8	0.24	C-5	6.05	0.0076
23	8/9/2018	140.96	Shoulder	8.2	8.0	0.29	PEM	6.30	0.0058
24	8/14/2018	140.56	TL	8.2	8.3	0.21	PEM	3.14	0.0067
25	8/15/2018	140.56	TL	8.9	8.9	0.18	PEM	6.67	0.0057

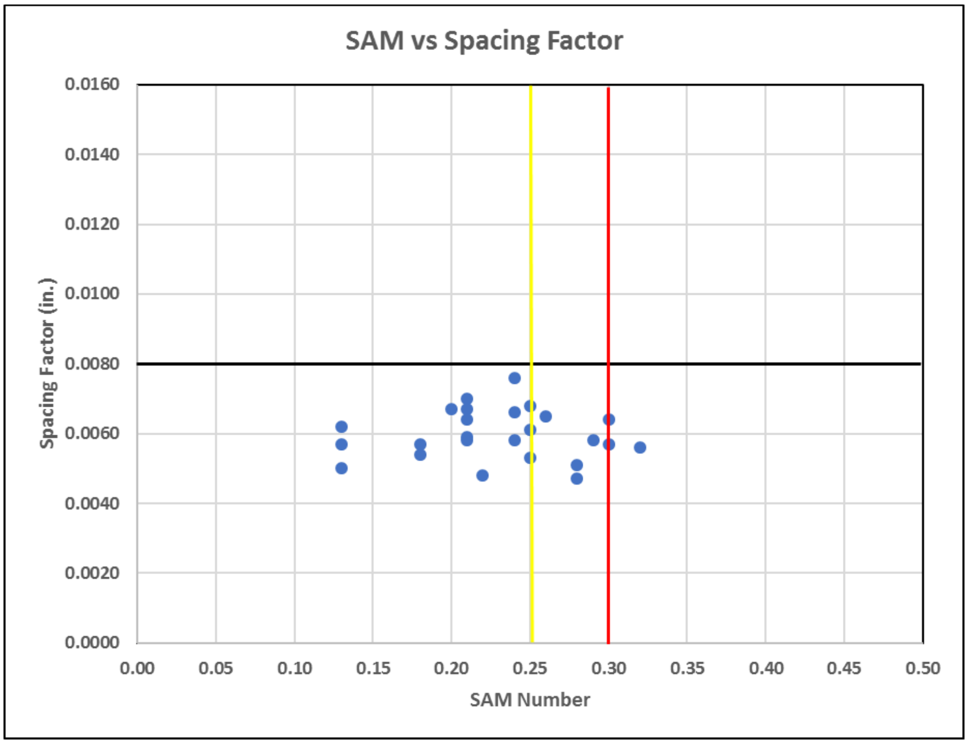

Figure 13: SAM Number versus Spacing Factor

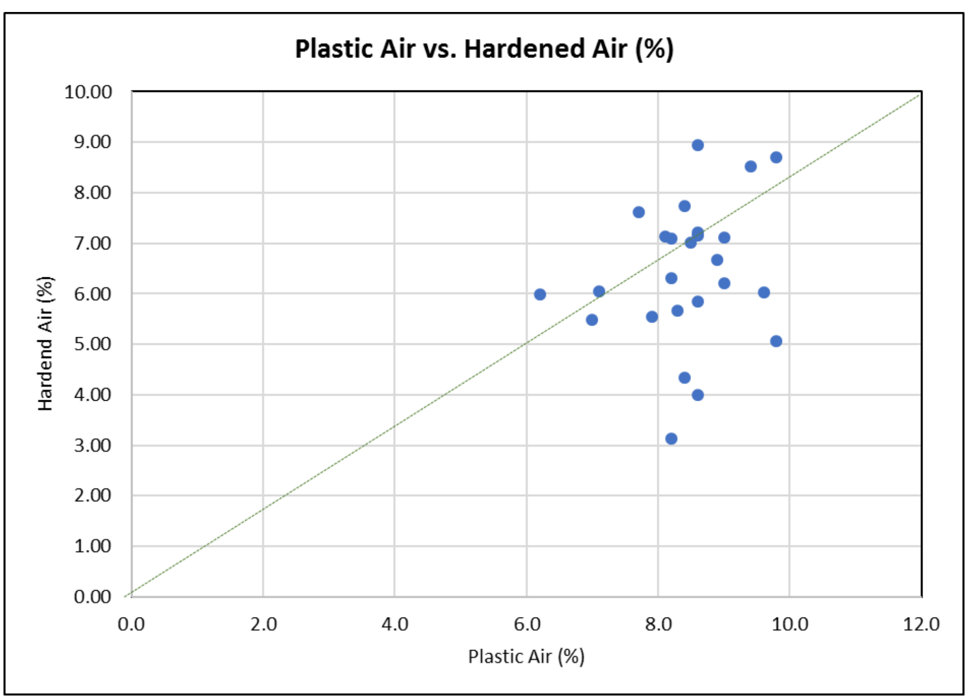

Figure 14: Plastic Air versus Hardened Air Content (%)

The plastic air content versus hardened air content was a little more variable than usual. There are a few samples that are way different than the plastic air content. No explanation for the variation was found.

Calcium Oxychloride (CaOXY) Formation Potential

Iowa State University obtained project samples of Portland cement and fly ash to determine the risk of oxychloride formation. Tests were run using a low temperature differential scanning calorimetry (LT-DSC) instrument. The potential for CaOXY formation decreased with increasing fly ash replacement. The replacement of 20% Class C fly ash reduces the CaOXY formation to the limiting value of 0.15 g/100 g. The test procedure may be found in the appendix.

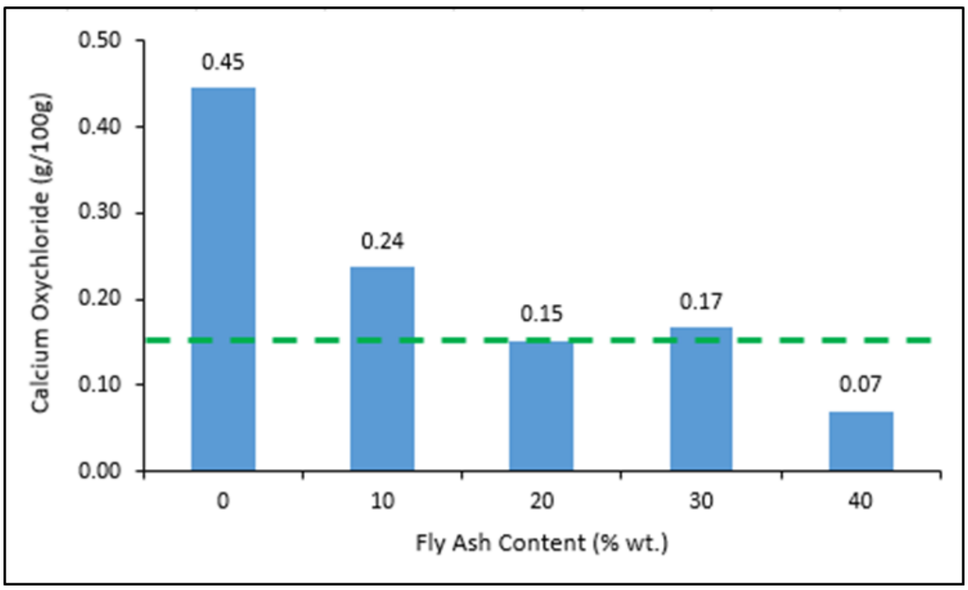

Figure 15: CaOXY formation for different fly ash replacement rates

MOBILE CONCRETE TRAILER (MCT) OBJECTIVES AND TESTING PLAN

The Federal Highway Administration (FHWA) (MCT) was also on the US 20 project as a part of the Performance Engineered Concrete Paving Mixtures pooled fund project (TPF-5(368)) and to demonstrate several other innovative technologies currently in the implementation phase of development including:

- Box Test – Measurement of workability.
- SAM – Measurement of air void characteristics of concrete.
- V-kelly
- Surface Resistivity – Rapid measurement to indicate permeability.
- Capillary Pressure Sensory System – Measurement used to prevent shrinkage cracking.
- MIT Scan 2 – Measure position of dowel bars.
- Microwave w/c

Traditional fresh concrete property tests and information was collected for the following:

- Slump
- Air content
- Unit weight

- Concrete Temperature
- Air Temperature
- Coefficient of Thermal Expansion (CTE)
- Air Void Analyzer (AVA)
- Compressive Strength
- 457
- Modulus of Elasticity (MOE)
- One sample each of cement and fly ash used in mix.

SCHEDULE

During July 9 – 13 and July 28 – August 1, 2018 the FHWA MCT performed shadow testing and to demonstrated several innovative technologies currently in the implementation phase of development on segment 4 of the U.S. 20 project in Iowa. This site visit was unique in that additional testing and monitoring was done using PEM implementation funds.

SAMPLING

Most of the sampling and testing was done at the contractor's Lucent Boulevard concrete plant; one sample was taken and tested on the grade. Table 4 provides the testing matrix for the project.

Table 4: Sampling Matrix

Date	Sample Day	Sample ID
7/10/2018	1	1-1, 1-2, 1-3, 1-4
7/11/2018	2	2-1, 2-2, 2-3, 2-4
7/12/2018	3	3-1, 3-2, 3-3, 3-4
7/28/2018	4	4-1, 4-2, 4-3*

*Sample taken and tested on the grade.

S&T at the plant included fresh concrete properties (slump, air content, temperature of concrete, etc.), SAM, AVA, coefficient of thermal expansion (CTE), 457, surface resistivity, microwave w/c, cylinders for compressive and flexural strengths, calorimeter and rapid chloride permeability test (RCPT). On the grade, S&T was collected for fresh concrete properties (by the contractor's testing consultant), SAM, AVA and 457. Field tests included MIT Scan, T2, capillary sensors in the pavement and instrumented maturity sensors in the pavement.

On August 8, 2018, an open house was held including presentations and demonstrations of MCT technologies. Participants included industry, Iowa DOT, IA FHWA Division Office and area chapters of the Concrete Paving Association. Approximately 20 people attended.

Figure 16. Open House Demonstrations

A close-out meeting was also held after the open house. Iowa DOT, IA FHWA Division Office, American Concrete Paving Association and representatives from Cedar Valley were in attendance. Project observations and findings were discussed and questions were answered based on the information that the MCT and contractor collected. Best practices observed on the project by MCT staff included:

- Vibration check – twice a day
- Air 6 -10%
- Low paste
- Optimized gradation
- Good air characteristics
- Vibrator checks
- MIT scan T2
- SAM/Box test

The contractor provided a letter outlining lessons learned while the MCT was on the project. The letter is included in the Appendix.

PEM TESTS-Contractor Perspective

The contractor provided comments on each of the PEM test methods and equipment. Comments overall were positive. Attached is a copy of the comments can be found in Appendix xx

SAM Air Meter

- Half day hands on training aided in familiarizing technician with test equipment and procedure.
- No improvements needed to test method. Concerns for durability of the gauge on the SAM.
- QC correlation testing requires heavy experience and attention to detail when performing side by side testing.

Box Test

- Was somewhat skeptical what the need for the test method.
- After reducing cement in Class A shoulder mix by 45 pounds, which none of the personnel thought would work, the box test showed good results and actually paved considerable quantity with good results.
- Several months later while bidding on another project with very tight specifications, considered mixes tested with the box test an invaluable tool.
- No improvements needed to the test method.

Resistivity Meter

- Simple test to perform while providing invaluable data to the owner and PC industry overall.
- No changes needed to the test method.

PEM TESTS-Agency Perspective

SAM Air Meter

- The agency was pleasantly surprised how well the test results were below the maximum of 0.30, especially with a newly trained technician.
- Still some small concern with correlation as a couple of the side by side tests performed between the contractor and FHWA were off from each other.

Box Test

- Same observations as the contractor. The test method can give good insight into mixes that may be at a reduced paste content or with unfamiliar aggregates.

Resistivity Meter

- Resistivity is a simple, non-destructive test that can be performed by anyone.
- Performing the formation factor (bucket test). The agency may be better suited to perform the testing. At 91 days, the contractor likely would be moving to another project and would have to haul all the buckets around with them.

SUMMARY AND RECOMMMENDATIONS

The FHWA Mobile Concrete trailer found that the current method of QMC mix design and quality control needs minimal areas requiring changes to improve concrete placement. Their recommendation was to include resistivity testing. Otherwise, the PEM testing may provide better indication of long-term durability of concrete pavement.

Based on the results of the demonstration project, the following recommendations

- Continue to investigate the PEM testing to determine the best methods for implementation
- Work with contractors to develop a reduced cement QMC mix design and validate with PEM test methods.
- Develop procedures to implement resistivity testing.

ACKNOWLEDGMENTS

Special thanks to the following people, without which, none of this information gathered would be possible.

Cedar Valley Corp -	Craig Hughes, John Quandahl, Bob Leon
CP Tech Center -	Peter Taylor, Gordon Smith
FHWA -	Mike Praul, Lisa McDaniel, Jagan Gudimettla, Jim Grove
FHWA (IA Division)	Lisa McDaniel for providing all the background data
Iowa DOT -	Josh Cedar, Steve McElmeel, Baron Hannah
ICPA -	Greg Mulder, Dan King
Snyder & Associates-	Jerod Gross

APPENDIX

Demonstration Project for
Implementation of Performance Engineered Mixtures/AASHTO PP 84
Project Application Form

Date : February 6, 2018

1. State Agency: Iowa Department of Transportation IDOT) **State Agency Contact(s):** Todd Hanson, Concrete Materials Engineer 515-239-1226, todd.hanson@iowadot.us **FHWA Division Office Contact(s):** Lisa McDaniel, FHWA-IA Division, 515-233-7307, Lisa.McDaniel@dot.gov
2. Project Location/Description: The US 20 four-lane project will be available for PEM testing. This is a 40-mile project improving US 20 to a four-lane facility in Woodbury, Ida and Sac counties. The paving projects began in 2016 and will finish in October 2018. Cedar Valley Paving Corp. has expressed interest in performance engineered mixes (PEM) and would like to be involved with testing. The FHWA Mobile Lab will also be on site.
3. Requested Funding: Indicate which category(ies) of funding you are seeking support for: **Category A:** $40,000 for incorporating two or more AASHTO PP 84-17 tests in the mix design/approval process. Shadow testing is acceptable. **Category B:** $20,000 for incorporating one or more AASHTO PP 84-17 test in the acceptance process. Shadow testing is acceptable. **Category C:** $20,000 for requiring a comprehensive QC Plan from the contractor that will be approved and monitored by the state. **Category D:** $20,000 for requiring the use of control charts, as called for in AASHTO PP 84-17.

4. **Description of What will be accomplished in each category:**

For each Category, from above, you are seeking funding support for, please discuss the requested information.

Category A: $40,000 for incorporating two or more AASHTO PP 84-17 tests in the mix design/approval process. *Since the project has already been let, The Iowa DOT will coordinate with CP Tech Center to obtain project materials and to develop a mix design for the contractor's Class A mix used on the shoulder. We would require SAM, Box Test, VKelly, Unit Weight, Bucket Test or CaOXY test (one of the tests that relates to the formation factor and critical saturation). Once the lab mix parameters have been established, the contractor may do a field trial batch to include SAM testing and either Box Test or VKelly or both to validate the lab mix. While the FHWA trailer is on the project, use this Class A PEM modified mix for up to a week to compare with the contractor designed mix (QMC) they are currently using. Contractor will perform SAM Testing, Box Test, and resistivity testing (formation factor) . <u>This is intended to be SHADOW Testing.</u>*

<u>Category B</u>: Identify which test(s) you will be evaluating, how your acceptance process will use the test(s) results, and how the use of the tests differs from your current process.

In addition to the requirements outlined in Iowa DOT's Standard Specifications (and other contract provisions as applicable), the AASHTO PP 84-17 tests listed below will be performed and evaluated as "shadow tests."

Fresh concrete:

For remainder of QMC paving and 1 week of Modified PEM A mix, Cedar Valley proposes to run

- *Plastic air test and SAM test side by side comparison on QC air tests*
  - *3-4 per day if running for entire project.*
  - *typically around 8 or more tests per day if only for 1 week.*
- *Plastic air and SAM test behind paver twice per week*
- *Temperature and unit weight twice per day*
- *One box test per day*
- *Cast one cylinder per day. Cylinders will be sent to Central Laboratory for resistivity testing (formation factor if we know how to run by then) and hardened air analysis (May need to send to Tyler Ley). Note air, SAM, unit weight and temperature at time cylinder is cast.*

CV will provide one extra technician to perform additional sampling and testing. CV will perform testing for one week with their current QMC mix design and one week with modified A mix on the shoulders. Iowa DOT will provide two SAM Air meters purchased through FHWA, which will become property of the contractor. Through these incentives *funds, it would be desired to purchase 1 or 2 SAMs not to exceed $5000.00. These SAMs would become the Contractor's at the conclusion of the project.*

Possibly have other two contractors working on US 20, purchase SAM meters, run comparison testing and cast cylinder for hardened concrete testing at minimum rate of two per day.

Hardened concrete:

- *<u>Resistivity testing</u>, performed on concrete cylinders per AASHTO T358 at ages of 28 and 90 days. Calculation of the ionic penetration (formation factor) of the concrete will be completed per Appendix X2 of AASHTO PP 84-17. Cast one 4 x 8 inch cylinder each time the SAM test in performed for resistivity testing. One 4 x 8 inch cylinder per day used for resistivity testing will be retained for hardened air testing.*

The contractor will perform QC testing using each of these methods and will submit these results to Iowa DOT. Iowa DOT will perform limited parallel testing, based on personnel availability. Iowa State University may also perform parallel testing to supplement ongoing PEM research. Results will be compared to recommended targets presented in AASTHO PP 84-17.

<u>All intended to be shadow testing</u>

Category C: $20,000 for requiring a comprehensive QC Plan from the contractor that will be approved and monitored by the state.

Iowa DOT currently requires a quality control plan for large paving projects. Contractor will update quality control plan to include requirements similar to FAA projects. Contractor will need to add SAM meter testing, bot test, and formation factor to their plan, including corrective action. In addition, the contractor will include quality control procedures for PWL plastic air content. (Shadow Testing)

Category D: $20,000 for requiring the use of control charts, as called for in AASHTO PP 84-17. *The Iowa DOT already requires control charts to plot aggregate combined gradations, air content before and after paver, unit weight, moistures, and w/c ratio. In addition to these, Iowa DOT will add the SAM air test, SAM number, Box Test, and Formation Factor. In addition, the contractor will monitor percent within limits (PWL) for plastic air specification compliance (Shadow Testing).*

5. Other Information:

Iowa State University and the FHWA trailer will assist the contractor and Iowa DOT personnel in this effort by providing:

- Development of shadow testing protocol
- Training of contractor and Iowa DOT personnel in use of the test equipment
- Target specification values for the resistivity test and SAM test, based upon past and ongoing research with locally available materials and mixtures, and
- Interface with other project stakeholders as requested.

DOT will have contractor's purchase SAM meters for testing. Have had one ready mix producer request a SAM meter to gain some experience with testing. They would cast cylinder for hardened air testing later.

FHWA Loan Program

- Will need at least 1 to 2 SAM meters
- Will need at least 3 Box Test equipment
- Will need at least 3 resistivity meters

Plastic Air %	SAM Air %	SAM #	Difference Air, %	Air Behind Paver, %	Air Loss %
9.0	8.8	0.13	0.2		
8.8	8.7	0.18	0.1	7.6	1.2
8.5	7.8	0.21	0.7		
8.0	8.1	0.18	0.1	6.8	1.2
8.0	8.7	0.10	0.7		
8.5	8.2	0.16	0.3		
8.8	8.4	0.16	0.4		
9.0	8.9	0.26	0.1		
8.6	8.3	0.25	0.3		
8.6	8.2	0.18	0.4		
6.3	6.0	0.20	0.3		
8.2	8.0	0.16	0.2		
7.7	8.1	0.21	0.4		
8.7	8.7	0.17	0.0	6.1	2.6
7.9	8.2	0.25	0.3		
8.6	8.8	0.24	0.2	6.7	1.9
8.7	8.8	0.24	0.1		
8.5	8.7	0.21	0.2	7.1	1.4
8.6	8.8	0.30	0.2		
9.6	9.4	0.26	0.2		
8.6	8.1	0.21	0.5		
7.8	8.4	0.24	0.6	6.6	1.2
9.8	9.7	0.22	0.1		
10.0	10.0	0.29	0.0		
8.5	8.8	0.18	0.3		
7.8	7.5	0.27	0.3		
8.2	8.3	0.21	0.1		
8.0	8.5	0.23	0.5		
8.6	8.9	0.28	0.3	7.2	1.4
9.0	9.1	0.13	0.1		
8.1	8.4	0.24	0.3		
8.4	8.5	0.13	0.1		
9.8	9.9	0.30	0.1		
7.4	7.0	0.19	0.4		
9.2	9.6	0.26	0.4		
8.6	9.0	0.19	0.4		

	PEM US 20 Iowa - Resistivity Testing					
		Days Since Casting				
#	3	7	14	28	56	91
1	5.95	7.41		11.07	16.75	22.48
2	5.61	6.01		8.98	13.41	18.05
3	6.41	6.83		13.15	19.76	26.18
4	5.40	7.10		11.96	19.06	24.27
5	5.78	7.38		7.50	16.07	21.22
6	7.63	8.51		12.87	17.55	22.92
7	6.31	7.76		11.54	14.59	20.74
8	6.30	6.96		9.78	13.86	19.92
9	6.56	7.66		10.86	15.76	22.06
10	7.10	7.77	8.24	10.95	15.66	21.23
11	6.67	8.46	8.88	11.80	16.28	22.80
12	8.28	8.32	8.87	12.44	17.50	21.71
13	6.82	7.36	8.80	12.94	17.92	23.36
14	5.94	7.08	11.04	13.93	18.52	24.09
15	7.99	8.13	8.79	9.97	16.25	20.35
16	7.38	7.96	9.60	11.74	18.82	23.10
17	6.49	6.94		12.66	18.52	20.97
18				12.39	17.67	19.55
19			11.22	13.59	18.85	23.07
20			10.67	13.08	18.78	22.33
21			10.52	11.73	18.25	22.37
22			8.36	10.11	14.89	18.71
23			9.43	11.33	16.17	21.75
24			8.36	10.13	17.89	22.41
25			8.59	10.64	23.17	23.17

BUCKET TEST											
Sample:	PEM1		Date Cast:	7/11/2018							
Project:	NHSN-020-1(123)--2R-97										
										1.1	
Test Date	**0**	**90**	**180**	**270**	**0**	**90**	**180**	**270**	**Average**	**Curing Co**	**Mass (g)**
7/12/18	3.1	3.3	3.2	3	3.3	3.3	3.2	3.2	3.2	3.5	3624.8
7/13/18	3.7	3.8	3.8	3.7	3.7	3.7	3.7	3.7	3.7	4.1	3633.7
7/16/18	4.8	4.5	4.7	4.6	4.8	4.7	4.7	4.6	4.7	5.1	3838.1
7/18/18	5.2	4.9	5.4	5.5	5.3	5	5.4	5.4	5.3	5.8	3638.9
7/25/18	6.5	6.3	6.6	6.4	6.5	6.3	6.9	6.3	6.5	7.1	3639.8
8/1/18	8	7.2	7.8	7.7	7.9	7.5	7.9	7.9	7.7	8.5	3646
8/8/18	9	8.3	8.6	8.7	9	8.4	8.8	8.8	8.7	9.6	3646.4
8/15/18	10.9	9.6	10.4	11	10.6	9.5	10.6	11	10.5	11.5	3646.6
8/22/18	11.1	9.8	11	10.8	11.3	9.9	10.9	10.6	10.7	11.7	3647
8/29/18	12.8	11.4	12.5	12.8	12.9	11.3	12.7	12.7	12.4	13.6	3647.8
9/5/18	13.9	12.7	13.9	13	13.9	12.2	13.9	13.6	13.4	14.7	3647.1
9/12/18	14.7	13.2	14	13.9	14.6	12.9	14.4	13.8	13.9	15.3	3647.2
9/19/18	16	14.6	15.6	15.8	15.8	14.3	15.6	15.4	15.4	16.9	3647.1
9/26/18	16.6	15.2	17.2	16.2	16.2	15.1	16.8	16	16.2	17.8	3647.5
10/3/18	18.7	16.9	19.3	18.5	18.1	18.4	19.2	17.4	18.3	20.1	3647.5
10/10/18	19.1	18	20.8	19.2	18.9	18.4	19.8	19.3	19.2	21.1	3649
							Formation Factor			2110.6	
Moist Room 7 Days	**In**		10/12/2018								
	Out		10/19/2018							**Weight**	3650
In Oven 72 Hrs	**In**		10/19/2018								
105 C	**Out**		10/22/2018							**Weight**	3422.1
Vacuum Chamber											
24 hrs			10/22/2018							**Weight**	3775.1

BUCKET TEST

Sample:	PEM2		Date Cast:		7/11/2018						
Project:	NHSN-020-1(123)--2R-97										
										1.1	
Test Date	**0**	**90**	**180**	**270**	**0**	**90**	**180**	**270**	**Average**	**Curing Co**	**Mass (g)**
7/12/18	3.4	3.5	3.1	3.1	3.4	3.6	3.1	3.1	3.3	3.6	3675.7
7/13/18	3.8	4	3.7	3.4	3.9	4.1	3.5	3.5	3.7	4.1	3683.3
7/16/18	4.7	5	4.4	4.3	4.6	4.9	4.4	4.3	4.6	5.0	3688.8
7/18/18	5.2	5.5	4.8	4.9	4.8	5.4	4.8	4.7	5.0	5.5	3689.8
7/25/18	6.2	6.8	5.8	6.1	6.3	6.9	5.8	5.9	6.2	6.8	3692.2
8/1/18	8	8	7.1	7.2	7.8	8.1	7.3	7.3	7.6	8.4	3697
8/8/18	8.4	8.9	8.2	8.1	8.5	9.1	8.1	8.1	8.4	9.3	3696.8
8/15/18	10.5	10.6	9.6	9.7	10.5	10.4	9.3	10	10.1	11.1	3696.9
8/22/18	10.6	11.1	10.4	10.1	10.9	11	10.2	10.2	10.6	11.6	3697.6
8/29/18	12.6	12.8	11.5	11.1	12.2	12.6	11.3	11.4	11.9	13.1	3697
9/5/18	13.3	13.3	13.3	13.1	13.5	13.3	12.6	12.7	13.1	14.5	3696.9
9/12/18	13.8	14.1	13.1	13	13.8	13.9	12.8	13.3	13.5	14.8	3698
9/19/18	14.8	15	13.9	14.2	15.4	14.7	13.7	14.5	14.5	16.0	3697.8
9/26/18	15.2	16.1	14.3	14.5	15.1	15.8	14.3	14.7	15.0	16.5	3698.5
10/3/18	17.9	17.9	16.8	18.1	16.8	17.8	17	18.5	17.6	19.4	3698.7
10/10/18	18.2	18.8	18.1	17.8	18	18.5	17.5	17.8	18.1	19.9	3699.3
						Formation Factor				1989.6	
Moist Room 7 Days		**In**	10/12/2018								
		Out	10/19/2018							**Weight**	3701
In Oven 72 Hrs		**In**	10/19/2018								
105 C		**Out**	10/22/2018							**Weight**	3476.6
Vacuum Chamber											
24 hrs			10/23/2018							**Weight**	3830.1

Iowa DOT PEM Project US 20 Woodbury Co. - Rapid Air457 Air Void Parameters

Cylinder #	Air Content (%)	Specific Surface (in-1)	Spacing Factor (in.)	Void Frequency (in-1)	Average Chord Length (in.)	Paste to Air Ratio
1	6.20	696.0	0.0065	10.79	0.0057	4.73
2	8.94	622.8	0.0053	13.91	0.0064	3.28
3	8.52	738.2	0.0047	15.72	0.0054	3.44
4	7.61	655.8	0.0059	12.47	0.0061	3.85
5	5.55	774.3	0.0061	10.75	0.0052	5.28
6	7.12	705.2	0.0058	12.55	0.0057	4.12
7	5.67	672.8	0.0070	9.55	0.0059	5.17
8	7.21	718.9	0.0057	12.97	0.0056	4.07
9	5.85	724.8	0.0064	10.60	0.0055	5.01
10	8.70	708.5	0.0048	15.42	0.0056	3.37
11	7.01	777.6	0.0054	13.62	0.0051	4.18
12	7.09	718.5	0.0058	12.75	0.0056	4.13
13	7.15	800.5	0.0051	14.30	0.0050	4.10
14	5.99	815.8	0.0056	12.22	0.0049	4.89
15	5.49	728.4	0.0066	10.00	0.0055	5.34
16	7.14	604.4	0.0068	10.79	0.0066	4.11
17	7.74	761.4	0.0050	14.73	0.0053	3.79
18	4.34	933.2	0.0057	10.14	0.0043	6.75
19	5.07	772.4	0.0064	9.80	0.0052	5.78
20	6.02	732.3	0.0062	11.03	0.0055	4.87
21	3.99	822.5	0.0067	8.21	0.0049	7.35
22	6.05	597.9	0.0076	9.04	0.0067	4.84
23	6.30	772.6	0.0058	12.17	0.0052	4.65
24	3.14	911.8	0.0067	7.17	0.0044	9.33
25	6.67	767.6	0.0057	12.80	0.0052	4.39

Potential for Calcium Oxychloride Formation; IA-PEM Project, LT-DSC Results

Testing was conducted to assess the SCM dosage required to reduce the risk of oxychloride formation in a construction project in Western Iowa on US 20 in 2018. Materials (cement and fly ash) were obtained from the site as part of a larger project evaluating test methods described in AASHTO PP 84.

Five paste mixtures were prepared in the PCC laboratory and tested for potential calcium oxychloride (CaOXY) formation in accordance with AASHTO T365 [1]. All pastes were proportioned with a fixed water-to-cementitious materials ratio (w/cm) of 0.40. The fly ash amount ranged from zero to 40% (by mass) in 10% increments. The paste specimens were prepared in a 1.5 L Hobart mixer. A slow rotator was used to eliminate bleeding of the paste samples while setting. The specimens were demolded 24 hr after casting and were exposed to an accelerated curing regime for up to 28 days as required by the method.

The paste specimens were ground to obtain powder samples at the end of the curing period. The test samples comprised 10 ± 0.5 mg of powder, sieved through a 75-µ mesh. The potential CaOXY formation was determined for powders exposed to 20% CaCl2 salt solution. A differential scanning calorimeter device, DSC 25, equipped with a low temperature kit, RCS 90 manufactured by TA Instruments was used.

Figure 1 presents a typical heat flow curve (blue line) of a cement paste sample and 20% CaCl2 solution. A 1:1 CaCl2 solution to paste powder ratio was selected to ensure a molar ratio of CH/CaCl2 smaller than 3 in order to consume calcium hydroxide (CH) completely, and to exhibit three distinct peaks: the melting of eutectic solids, the melting of ice, and the phase transformation associated with CaOXY.

Computer software with the LT-DSC instrument was used to integrate the heat flow versus temperature curve associated with the CaOXY melting phase transition (green line in Figure 1). The magnitude of the drop in the cumulative heat curve was calculated and the amount of potential CaOXY formation (normalized per 100 g of cementitious paste) was determined using Eq. 1 [1]:

$$M_{CaOXY} = \frac{\Delta H}{L_{CaOXY}} \times 100 \qquad \text{Eq. 1}$$

where: M_{CaOXY} is the mass in g of CaOXY per 100 g of cementitious paste, g/100g; ΔH is the latent heat absorbed during CaOXY phase transition, J/g; and L_{CaOXY} is the specific latent heat associated with pure CaOXY phase transition, 186 J/g.

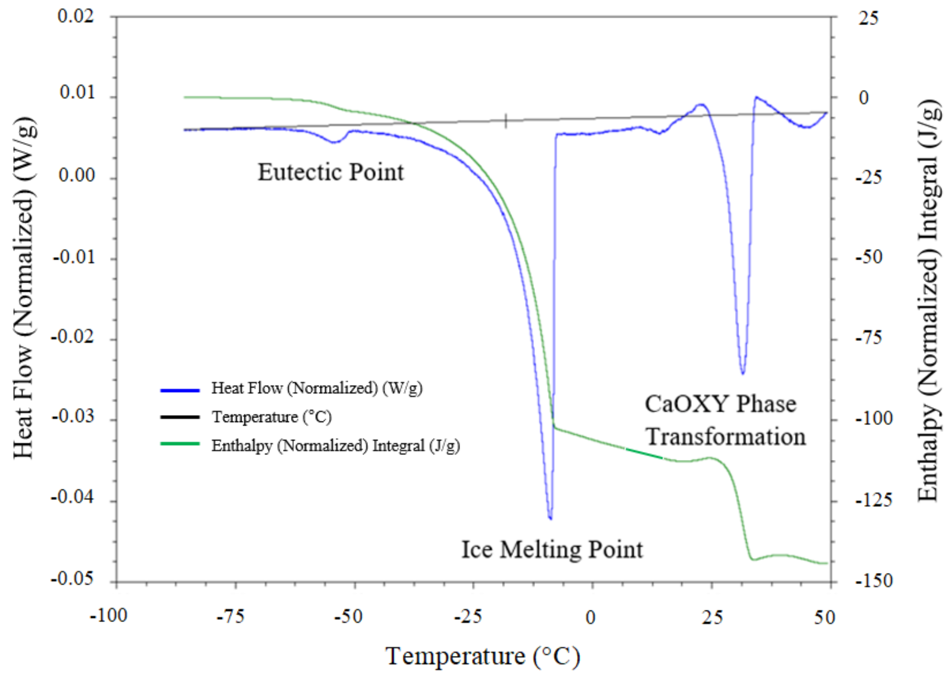

Figure 1. A typical low temperature differential scanning calorimetry (LT-DSC) curve

Results obtained from testing the IA-PEM samples are presented in Figure 2. A reduction in CaOXY formation was observed with an increase in fly ash replacement rate. This was in line with previous observations of the research team and the data available in literature [2]. It is reported by [2, 3] that limiting the CaOXY formation to values lower than 0.15 (g/100g) can secure proper durability against oxychloride. Results suggest that, for the materials evaluated, the use of a 20% fly ash (by mass) reduces the risk of deterioration due to oxychloride formation and can secure desired performance.

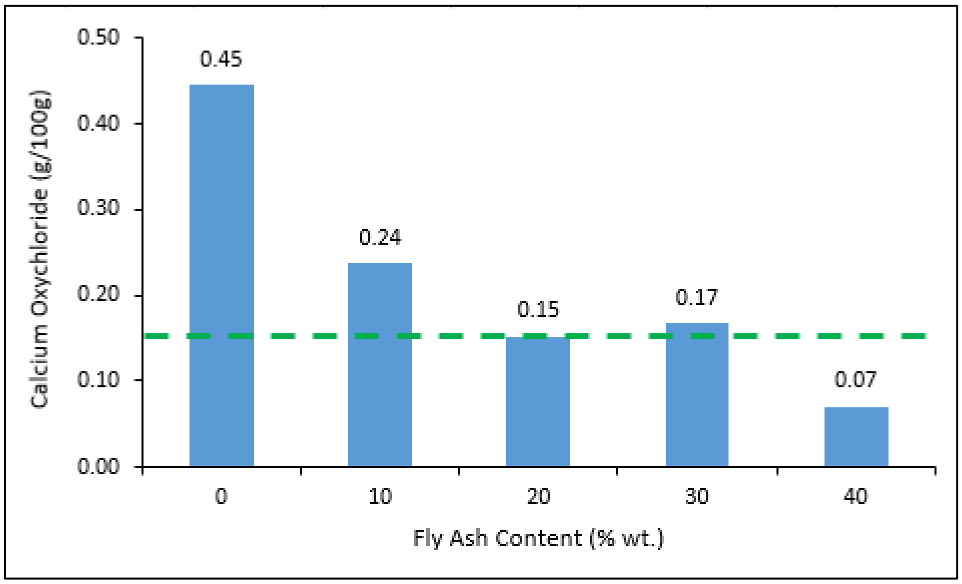

Figure 2. CaOXY formation for different fly ash replacement rates

1. AASHTO T365. Quantifying calcium oxychloride amounts in cement pastes exposed to deicing salts. American Association of State Highway and Transportation Officials, (2017), Washington, D.C.
2. Monical, J., Villani, C., Farnam, Y., Unal, E., & Weiss, W. J. (2016). Using Low-Temperature Differential Scanning Calorimetry to Quantify Calcium Oxychloride Formation for Cementitious Materials in the Presence of Calcium Chloride. Advances in Civil Engineering Materials, 5(2), 142-156.
3. AASHTO PP84. Standard practice for developing performance engineered concrete pavement mixtures. American Association of State Highway and Transportation Officials, (2017), Washington, D.C.

Cedar Valley Corp., LLC
2637 Wagner Road
Waterloo, Iowa 50704

August 20, 2018

Mr. Rabindra Pariyar, EI
Snyder & Associates, Inc.

Rabi,

After recently hosting a site visit and "open house" with the FHWA Mobile Concrete trailer on our U.S. Highway 20 project we wanted to take a moment and pass on the following thoughts.

We had of course hoped to learn more about new test methods and Performance engineered mixes and have the opportunity to expose our construction crews to future material testing procedures and emerging technologies.

We gained far more in knowledge than it cost us to host the program. Jagan Gudimettla was very informative, and easy to work with concerning PEM testing procedures.

Mr. Gudimettla was very accommodating of his time explaining not only the testing procedures, but why they added value to the paving process. He was just as engaged explaining the processes to our senior staff as he was explaining it to our construction crews (who on numerous occasions wanted to see how a concrete cylinder was tested for strength).

I have to admit that in the beginning I was skeptical concerning any reason to perform a "box test", most of us can look behind the paver and see pretty quick how the mix is performing. After performing the test on a PEM mix that dropped 45 pounds of cementitious per cubic yard out of the QMC mix we were paving with "the light came on". None of us thought that we could pave with a mix like that, we were prepared to start adding cementitious in 10-pound increments until we thought it was something we could pave with. After performing the box test on the mix, we were very pleasantly surprised.

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www.cedarvalleycorp.com

Build with the best!

We paved six days of approximately two miles per day of PCC shoulders using the mix and it performed very well. To our surprise the maturity curve for the mix performed so close to the original QMC mix that opening strengths were not an issue (less than 48 hours).

I can now think of several instances in the past that being able to perform a "Box test" prior to paving, could have been invaluable.

Performing the SAM test was daunting to our staff, all of our staff, after "seeing" the procedure for the fist time. After the first day, the process was not an issue. One of our grade inspectors performed the test as fast and accurate as some of the staff can perform a "common" air test (the young man started the season as a laborer).

Maybe most of all the site visit exposed our staff to a group of professionals that were as excited about quality pavements as we try to be. For our staff to be exposed to that and have the opportunity to interact with Jagan and his staff was an unexpected benefit (when you have Jagan Gudimettla and Jim Grove in the same spot, you can learn a lot about PCCP, good and bad).

In closing, this was a great experience for our company. Our concrete paving crews that actually BUILD the pavement got to see how important quality is on a national level. That is a strong message for the folks building the work.

Sincerely;
Craig Hughes
V.P. Operations

Cedar Valley Corp., LLC
2637 Wagner Road
Waterloo, Iowa 50703

December 17, 2018

Mr. Todd Hanson, P.E.
PC Pavement Engineer
Iowa Department of Transportation
800 Lincoln Way
Ames, Iowa 50010

RE: Pooled Fund Project TPF-5(368)
NHSN-020-1(123)—2R-97
U.S. Highway 20 PEM Testing

Mr. Hanson,

The following comments are offered concerning the PEM testing performed by Cedar Valley Corp., LLC on the above referenced project.

SAM Air Meter
Our initial introduction to the SAM was daunting to say the very least. We requested a training day with Ash Grove cement technical staff as they are very familiar with SAM testing procedures. After a half day, hands on training session at one of our central mix batch plants we were not nearly as overwhelmed.

- **Improvements** – We do not have any recommended improvements on the test method. Hands on training followed by daily field use turned the SAM into just another QC check. The SAM meter as a stand-alone piece of equipment could use some "hardening" concerning the gauge portion of the equipment. A "stern look" is about all it takes to break it of the lid. At approximately $500.00 to replace (and they want the old one back before they will replace it), it needs some attention to be "field approved".
- **QC feedback** – Performing "side by side" tests, with expectations of "correlation" depends heavily on the experience, attention to detail and desire of the individuals performing the test.

Box Test
This test was met with a certain amount of skepticism initially (mine included), concerning a need for the test. After dropping 45 pounds per cubic yard of cement out of our QMC mix (which none of us thought would go well, at all), and performing the box test, we were astonished and actually paved a considerable quantity with the PEM adjusted mix with very good results. Several months later while bidding a project with very tight specifications we considered mixes tested with a BOX TEST as an invaluable tool prior to sending concrete to a paving spread. We can think of no improvement to this test.

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Resistivity Meter
This test was simple to perform for the contractor while providing invaluable data to the project "owner" and the PC paving industry overall. How the industry can disseminate the information gained, concerning the countless variations of materials and how they interact with the limitless natural and man-made conditions seems to be the real challenge.

I have also included a letter I sent to the PC Tech Center this summer concerning the PEM testing performed on Highway 20 this year as well as a visit by the FHWA Mobile Concrete Trailer on the same project. We considered both very interesting and a great learning opportunity for our staff, and interested industry members.

Sincerely;
Cedar Valley Corp., LLC
Craig Hughes
V.P. Operations

Submit to:
Michael F. Praul, P.E.
Senior Concrete Engineer
Office of Preconstruction, Construction, and Pavements (HICP-40)
michael.praul@dot.gov