MnDOT High Performance & Contractor Mix Designs

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DEPARTMENT OF TRANSPORTATION

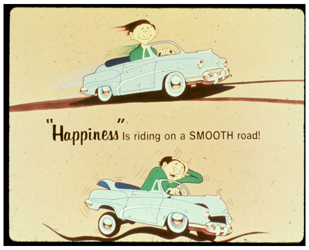
Today

- Why High Performance Concrete
- High Performance Bridge Mix Designs
- Transition to Contractor Mix Designs
- Strength as a Requirement
- FHWA Performance Engineered Concrete Mix Designs Initiative
- The Future of Testing and Acceptance of Concrete

Why High Performance Concrete?

FHWA Moving Ahead for Progress in the 21st Century

- In 2013, MAP-21 established performance targets the States must meet
- In 2017, FHWA finalized MAP-21 performance measures requirements effective in 2018



MAP-21 Performance Targets

- Proposed pavement condition measures
  - % of Interstate pavements in Good condition
  - % of Interstate pavements in Poor condition
  - % of non-Interstate NHS pavements in Good condition
  - % of non-Interstate NHS pavements in Poor condition
- No more than 5% poor for the Interstate System

- Proposed bridge condition measures
  - % of NHS bridges by deck area in Good condition
  - % of NHS bridges by deck area in Poor condition
- Maintain bridges on the NHS to have no more than 10% of the overall bridge deck area of bridges classified as Structurally Deficient

High Performance Bridge Mix Designs

High Performance Bridge Deck Mixes

Performance Mix Designs - All Bridge Deck Mixes

- Contractor Designed
  - 3YHPC-M/3YHPC-S (monolithic/structural) with…
    - Fibers
    - Internal Curing (IC)-lightweight sand
    - Lightweight Concrete-lightweight coarse aggregates
    - Self Consolidating Concrete (SCC)

3YHPC-S/3YHPC-M

Table HPC-4
High Performance Bridge Deck Concrete Mix Design Requirements

Concrete Grade	Mix Number *	Intended Use	w/c ratio	Target Air Content	Maximum %SCM (Fly Ash/Slag/ Silica Fume/ Ternary) ‖	Slump Range †, *inches*	Minimum Compressive Strength, f'c (28-day)	3137 Spec.
HPC	3YHPC-M	Bridge Deck – Monolithic	0.35-0.45	6.5%	30/35/5/40	1 - 4	4000 psi	2.D.2
	3YHPC-S	Bridge – Structural Slab						

* Provide a Job Mix Formula in accordance with 2401.2.A.7. Use any good standard practice to develop a job mix formula and gradation working range by using procedures such as but not limited to 8-18, 8-20 gradation control, Shilstone process, FHWA 0.45 power chart or any other performance related gradation control to produce a workable and pumpable concrete mixture meeting all the requirements of this contract.

‖ The individual limits of each SCM shall apply to ternary mixtures.

† Keep the consistency of the concrete uniform during entire placement.

High Performance Bridge Deck Mixes

Performance Mix Designs - All Bridge Deck Mixes

- Contractor Designed
  - 3YLCHPC-M/3YLCHPC-S (monolithic/structural)
    - Straight Cement

3YLCHPC-S/ 3YLCHPC-M

No Flyash!!!

Working with the KU (Kansas University)

Table HPC-2
High Performance Bridge Deck Concrete Mix Design Requirements

Concrete Grade	Mix Number *	Intended Use	w/c ratio	Air Content	Cement Content ‖	Slump Range †, *inches*	Minimum Compressive Strength, f'c (28-day)	3137 Spec.
HPC	3YLCHPC-M	Bridge Deck – Monolithic	0.42-0.45	8.0% ±1.0%	500-535lbs./yd^3	$1^1/_2$ - 3	4000 psi	2.D.2
	3YLCHPC-S	Bridge – Structural Slab						

* Provide a Job Mix Formula in accordance with 2401.2.A.7 per these special provisions. Use any good standard practice to develop a job mix formula and gradation working range by using procedures such as but not limited to 8-18, 8-20 gradation control, Shilstone process, FHWA 0.45 power chart or any other performance related gradation control to produce a workable and pumpable concrete mixture meeting all the requirements of this contract.

‖ The cement content shall be 100% Portland Cement.

† Keep the consistency of the concrete uniform during entire placement.

Additional Requirements

- Trial Batching
- Trial Placement
- Slab Placement and Curing Plan
- Pre-Placement Meeting

Transition to Contractor Mix Designs

Why Contractor Mix Designs?

- New and improved materials and technology
- Allow increased use of supplementary cementitious materials
- Allow more flexible use of admixtures
- Producers know and understand their materials better than MnDOT
- More cost effective mixes
- Transition to performance based mixes

Transfer of Responsibility

- The Contractor assumes full responsibility for the mix design and performance of the concrete.
- The Engineer determines final acceptance of the concrete for payment based on test results, satisfactory field placement and performance.

Current Mix Design Process

- Allows Producers to Submit Mix Designs meeting one of the following:
  - Level 1 - Mix designs limited to a maximum of 15% fly ash with some additional conditions
  - Level 2 - More innovative mix designs provided a suitable experience record or trial batching with some additional conditions

Strength as a Requirement

2016 Lessons Learned

- Fabricating Cylinders
- Moist Curing Environments
- Curing and Handling Cylinders
- Transporting Cylinders
- Spec was lacking enough guidance on interpretation and acceptance of Strength Results

Low Cylinder Strengths

- Cylinder tops not perpendicular to sides
- Plan ahead! Cure cylinders on a level surface

Saw Slice

Contractor Provided Moist Curing Environment

- The Contract requires providing moist curing environments of adequate size and number for <u>initial and intermediate curing (first 7 days)</u> of concrete cylinders
- For each separate curing environment, provide a calibrated waterproof digital temperature recording device that records the daily maximum and minimum ambient temperatures for the previous 7 days.

Curing and Handling Cylinders

Variables Affecting Strength NRMCA Pub. 179 – David Richardson

- Among the factors influencing compressive strength of concrete as delivered to the jobsite, <u>temperature is of major importance</u>
  - Non-compliance to code requirements pertaining to initial curing temps contributes to strength variations of as much as 1450 psi
  - Adequate protection of cylinders during the first 24 hours after casting is essential
  - The use of a water container greatly diminished the effect of high exterior temperatures
  - The use of a curing box is greatly recommended for important project
  - High ambient temperature influence concrete temperature, and especially macro pores formation.

Low Cylinder Strengths

Insufficient Consolidation
Up to 61% Reduction

Excessive Tapping
Up to 6% Reduction

Table 1-Measured strength reduction by nonstandard conditions

Variable	Strength loss, %	Lab or field
Convex ends	Up to 75	Lab
Insufficient consolidation	Up to 61	Field
Immediate freezing for 24 h	Up to 56	Field
Rubber cap, no restraint	Up to 53	Lab
Weak, soft capping compound	Up to 43	Lab
Flat particle, vertical orientation	Up to +0	Field
Concave ends	Up to 30	Lab
Rough end before capping	Up to 27	Field
Seven days in field, warm temperature	Up to 26	Field
Reuse of plastic molds	Up to 22	Lab
Cardboard mold	Up to 21	Field
Seven days in field at 73 F no added moisture	Up to 18	Field
Plastic mold	Up to 14	Field
Rough end, air gaps under cap	Up to 12	Field
Convex end capped	Up to 12	Field
Eccentric loading	Up to 12	Lab
Out-of-round diameter	Up to 10	Field
Ends not perpendicular to axis	Up to 8	Field
Rough handling	Up to 7	Field
Three days at 37 F, mixed at 73 F	Up to 7	Field
One day at 37 F, mixed at 46 F	Up to 7	Field
Excessive tapping	Up to 6	Field
Thick cap	Up to 6	Lab
Sloped end, leveled by cap	Up to 5	Field
Wet mixture subjected to vibrations	Up to 5	Field
Chipped cap	Up to 4	Lab
Reinforcing bar rodding	Up to 2	Field
Insufficient cap cure	Up to 2	Lab
Slick end cap	Up to 2	Lab
Slow loading rate	Up to 2	Lab

NRMCA Pub. 179 – David Richardson

Low Strengths Related to Curing Issues

7-days in Field warm Temps
26% Strength Reduction

7-days in field at 73ºF
w/o moist cure environment
18% Strength Reduction

Table 1-Measured strength reduction by nonstandard conditions

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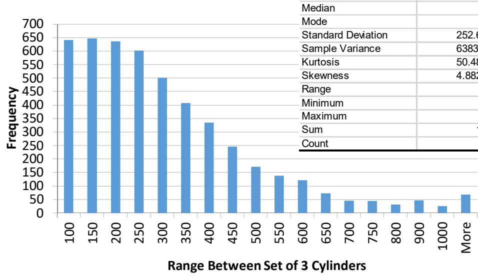
NRMCA Pub. 179 – David Richardson

2017 Lessons Learned

- Curing and Handling Cylinders
- Variability within a set of 3 cylinders
- Variability of a mix design on a single project
- Dispute Resolution Process

Concrete Strength Variation Between Three Cylinders from a Single Strength Test

Mean	297.2636193
Standard Error	3.650301068
Median	240
Mode	140
Standard Deviation	252.6630712
Sample Variance	63838.62757
Kurtosis	50.48352938
Skewness	4.882290776
Range	4660
Minimum	0
Maximum	4660
Sum	1424190
Count	4791



2018 Specification 2461

Strength Variability Set of 3 Cylinders

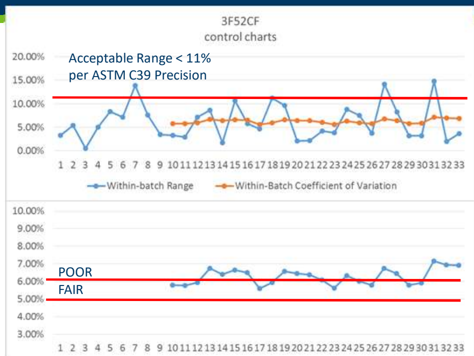
- If 1 of the set of 3 cylinders shows variability >10% outside of the initial calculated three cylinder average strength, the report software will average the remaining 2 cylinders and report as the 28-day strength.
- Example: 3500psi + 4000psi + 4200psi = 3900psi average

  New Average 4000psi + 4200psi = 4100psi

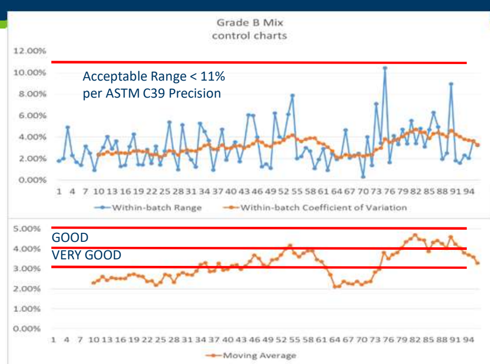
If 2 or more of the set of 3 cylinders shows a variability >10% outside of the initial calculated average strength, the Engineer will use all 3 cylinder results to calculate the 28-day strength.

- Example: 3200psi + 4000psi + 4500psi = 3900psi average

Evaluating Control Charts – Example 1



Evaluating Control Charts – Example 2



Erroneous Cylinder Test Results

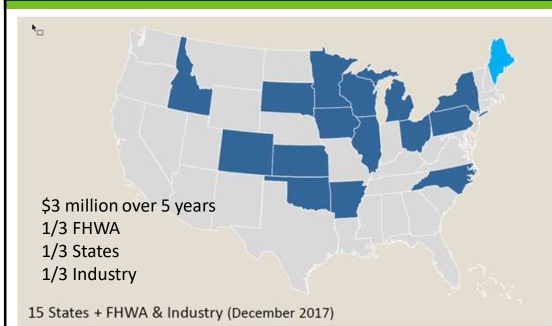
- Cylinders remain in field greater than 7-days. **(Bring cylinders into lab at least once per week!)**
- Cylinders delivered to the lab without lids and have dried to a whitened state
- Improper handling/field curing of cylinders
- Improper testing of the cylinders (not taken to complete failure)
- Cores taken from deficient structure have shown adequate strength… If cores pass Agency pays coring and third party testing.

FHWA Performance Engineered Concrete Mix Designs Initiative

Is this something new?

- MnDOT has participated in the following:
  - FHWA ETG on development of Performance Engineered Mixes (2013-now)
  - Champion States Group on validation of PEM performance tests (2015-2017)
    - AET supported with PEM field testing
- AASHTO PP84-17, "Performance Engineered Concrete Pavement Mixtures"

TPF5(368) Pooled Fund States



What is PEM?

Performance – Choosing what we need

Engineered – Delivering what is needed

Mixtures – Let's engineer our mixtures to perform

The Concrete

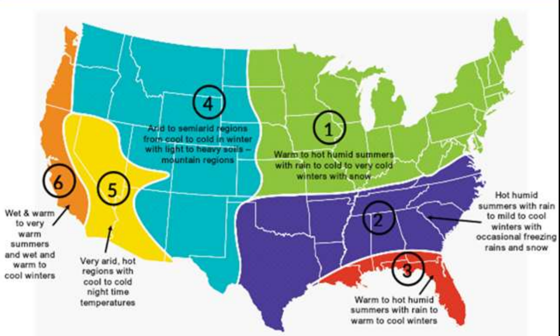
Gray .... ☑

Strong .... ☑

Cracked .... ☑

Slide from Peter Taylor

One Mix Design Doesn't Fit All



A Better Specification

Require the things that matter

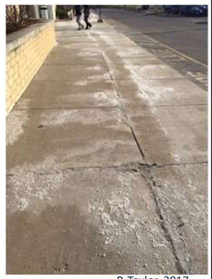
- ✓ Transport properties (everywhere)
- ✓ Aggregate stability (everywhere)
- ✓ Strength (everywhere)
- ✓ **Cold weather resistance (cold locations)**
- ✓ **Shrinkage (dry locations)**
- ✓ Workability (everywhere)

P. Taylor, 2017

Critical Properties

Transport properties (permeability)

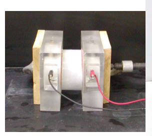
- ✓ All deterioration mechanisms involve fluid movement
- ✓ Keep water out = longer life
- ✓ Measurement has been difficult
  - ✓ Boiled water
  - ✓ RCPT

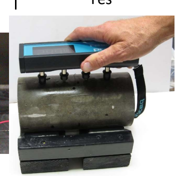


P. Taylor, 2017

Moisture penetration

	w/cm	RCPT Value	Formation Factor
Test method	-	AASHTO T 277	AASHTO T 358
Value	0.45	< 2000	> 500
Approval?	Yes	Yes	Yes
Acceptance?	Yes	Yes	Yes



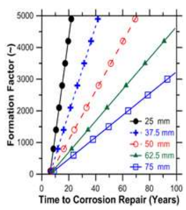


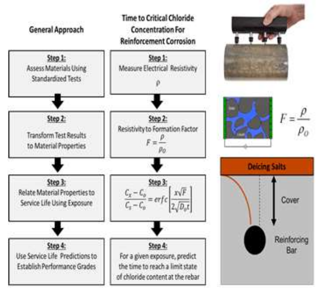
What is the formation factor?

- It is a true measurement of how hard it is for ions to move through concrete.
- If we can get this information then it will be much easier to predict moisture penetration into concrete and the subsequent long term performance.

Formation Factor

- We can relate/obtain the F Factor from resistivity and relate it to depth of chloride penetration





Slide courtesy of Weiss et al. 2016c

Critical Properties

Aggregate Stability

- ✓ If aggregates expand = damage
  - ✓ Alkali aggregate reaction
  - ✓ D-Cracking

P. Taylor, 2017

Critical Properties

Strength

- ✓ Strong enough (But not much more) It comes along for the ride
- ✓ Beware of shrinkage, high heat

P. Taylor, 2017

Strength

Choose one!

	Flexural Strength	Compressive Strength
Test method	AASHTO T 97	AASHTO T 22
Value	4.1 MPa 600 psi	24 MPa 3500 psi
Approval?	Yes	Yes
Acceptance?	Yes	Yes

Critical Properties

Cold Weather Resistance

- ✓ Freeze-thaw
  - ✓ Entrained air
- ✓ De-icing salts
  - ✓ Sufficient SCM


P. Taylor, 2017

Freeze Thaw durability

	w/cm	Air void volume	Air void system	Time to Critical Saturation
Test method	-	AASHTO T 152, T196, TP 118	AASHTO TP 118	-
Value	< 0.45	5 to 8%	≥ 4% Air SAM ≤ 0.20	30 Yrs
Approval?	Yes	Yes	Yes	Yes
Acceptance?	Yes	Yes	Yes	No



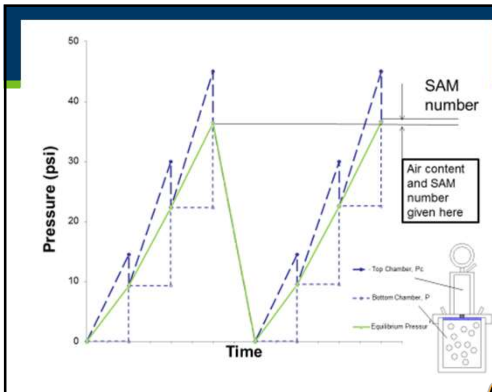
Super Air Meter (SAM)

AASHTO TP 118

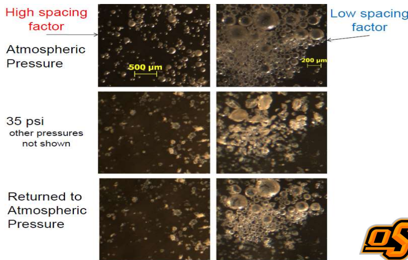
www.superairmeter.com

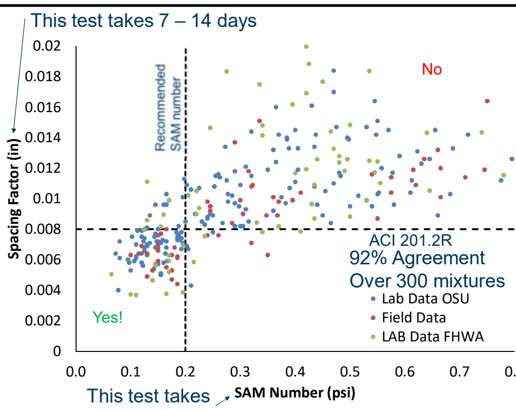
How does it work?

- You use multiple pressure steps instead of one.
- The meter measures the air volume and the bubble size distribution
- The test takes 5-10 minutes



- 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
- SAM measures the bubbles that dissolve and don't come back.





Critical Degree of Saturation

- Cast concrete and keep sealed for 14 days
- Measure the cylinder mass after demolding
- Place three concrete cylinders in lime water
- Measure their mass at 5 days
- Measure their mass again every 10 days until they are 60 days old
- Oven dry cylinder and take mass
- Vacuum saturate cylinder and take mass
- Calculate the time to critical degree of saturation.

Critical Properties

Shrinkage

- ✓ Random cracking
- ✓ Warping

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Dimension changes and cracking from drying shrinkage

Test method	Ring Test AASHTO T 334	Dual Ring AASHTO TP363	Modeling -
Value	crack free	σ < 60% f'r	5, 20, 50% cracking prob
Time	180 days	7 days	
Approval?	Yes	Yes	Yes
Acceptance?	No	No	No

Critical Properties

Workability

- ✓ Not too wet
- ✓ Not too dry

P. Taylor, 2017

Box Test

- A simple test that examines:
  - Response to vibration
  - Filling ability of the grout
  - Ability of the slip formed concrete to hold a sharp edge (cohesiveness)
- **The Slump test can not tell us this!**
- In most cases, the box test has proven out very workable concrete mixes

Slide courtesy of Dr. Tyler Ley, OSU

Key Component - Quality Control

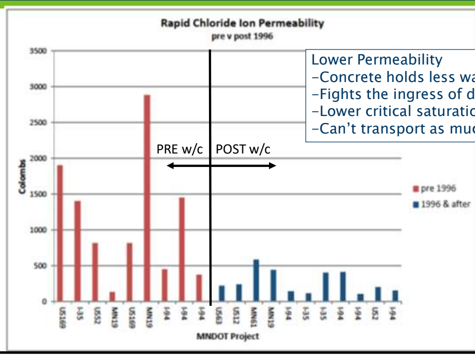
- Why don't we track how our concrete varies?
  - Unit weight
  - Air content/SAM
  - Water content
  - Formation Factor
  - Strength
- This is important information that we are ignoring.
- PEM will provides guidance for QC
  - Testing targets, frequency, and action limits
  - Guidance will expand on this

Slide from Tom Cackler

Minnesota Department of Transportation (MnDOT) vs. Performance Engineered Mixes (PEM)

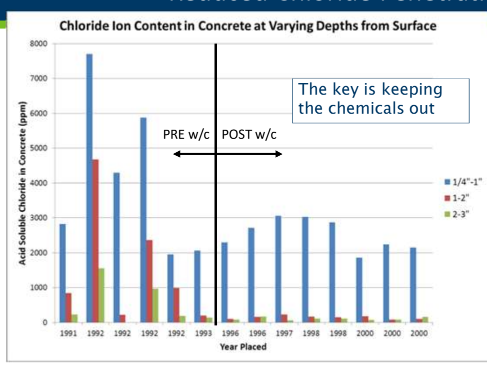
PEM	MnDOT	Spirit of PEM
Strength	• Maximum w/c ratio Incentive	X
Reduce Cracking	• Optimized gradations Incentive • Increased SCM's • Maximum w/c ratio Incentive	X
Durability**	• Optimized gradations Incentive • Increased SCM's • Maximum w/c ratio Incentive • **Fresh Air Content****	X
Transport Properties**	• Optimized gradations Incentive • Increased SCM's • Maximum w/c ratio Incentive • **Permeability/Resistivity****	X
Aggregate Stability	• Aggregate Quality Incentive	X
Workability	• Contractor Controlled	X

Transport Properties – Reduced Permeability



Lower Permeability
- –Concrete holds less water
- –Fights the ingress of deicers
- –Lower critical saturation level
- –Can't transport as much water

Transport Properties – Reduced Chloride Penetration



The key is keeping the chemicals out

The Future of Testing and Acceptance of Concrete

What Research has MnDOT done?

2013 – present ~ Participation in Multi-State Pooled Funds

2015 -2016 ~ Contracted with American Engineering Testing to use SAM and Box Testing on paving projects (2 – 4 tests per project)

2017 ~ MnDOT Grad Engineer (6 to 8 SAM tests per project)

Summer of 2017 – MnDOT SAM Testing

- Feasibility of the SAM in the Field
  - Test out the additions to the SAM
- Compare to current Pressure Meter
- Test 2 SAM's at the same time
- Compare SAM # to Hardened Air
- Write a shadow specification

Hardened Air Void Analysis

From Hover

Use of SAM for Trial Batching

- AET Batched multiple mix designs for MnROAD Reconstruction this summer
- All materials the same
  - 1 batch failed the SAM testing, All other mixes passed
  - Rebatched using the same materials – SAM failed
  - Removed the VMA and the SAM passed
  - Why? Not sure

2/15/2018 Optional Tagline Goes Here | mndot.gov/ 63

Use of SAM for Extended Delivery Time Project

- MnDOT specifications require concrete placement within 90 minutes of batching with no additional water at 60 minutes
- Allow testing to extend delivery to 120 minutes
  - Trial/Field Batch
  - Plastic and Hardened Air Required

What's Next for Super Air Meter?

- Get the SAM in the Contractors Hands!
  - Focusing on Paving First
- FHWA Equipment Loan Program
  - MnDOT has requested 3 or 4 SAMs for use during the 2018 season

SAM Shadow Specification

- Plastic Air Content – Target 7% (+2%/- 1.5%)
- SAM Number (Information Only)
  - < 0.25 and minimum air content of 4.0%
  - > 0.25 to < 0.30 make adjustments
  - ≥ 0.30 immediately sample the concrete from the same location and fabricate one (1) 4 in x 8 in cylinder.

MnDOT SAM Implementation Plans

- 2019 – Let pilot paving projects using a combination of plastic air content and SAM
- 2020 – Full implementation of SAM Specifications on paving projects
- 2019 – Start looking at Ready-Mix focusing on bridge decks

What's Next for PEM Concrete Paving?

- Applied for $100,000 FHWA Incentive Program to Implement Performance Engineered Mix Designs for Concrete Paving
  - Will add to a 2018 concrete paving project by Change Order
  - FHWA Mobile Testing Lab to come to paving project in Summer 2018
  - FHWA Quality Workshop in Fall/Winter 2018
    - 30-40 participants (50% Agency/50% Industry)

PEM – Mix Design Evaluation

- *MnDOT doesn't currently require trial batching of the concrete mix design. We would require trial batching specifically for this project. We would require SAM, Maturity for Flexural Strength, Box Test, VKelly, Unit Weight, Bucket Test or CaOXY test (one of the tests that relates to the formation factor and critical saturation). This is intended to be SHADOW Testing.*

$40,000

PEM – Acceptance Tests

- *Section 6.3 Strength – I prefer not to put a strength requirement into the contract as I feel that is a step backward for MnDOT Specifications.*

$20,000

PEM – Acceptance Tests

- *Section 6.4 Shrinkage – I do not have concerns of shrinkage or curling and warping and do not want to specify anything in this category. I have talked to the industry about 25 or 26% paste contents. We currently provide an incentive for optimized aggregates (tarantula curve) and would continue to utilize that incentive.*

$20,000

PEM – Acceptance Tests

- *Section 6.5 Durability – MnDOT would use the Super Air Meter and the SAM spec (MnDOT currently uses the Type B Pressure Meter with an air content range). I would likely increase the SAM from 0.20 to 0.25 and reject at 0.30 which is consistent with Tyler Ley work and recommendations. This is intended to be SHADOW Testing. Through these incentives funds, it would be desired to purchase 1 or 2 SAMs not to exceed $5000.00.*

$20,000

PEM – Acceptance Tests

- *Section 6.6 Transport Properties – MnDOT would specify a maximum w/c ratio and use the new w/c device currently in development by Oklahoma State (MnDOT currently uses AASHTO T318 microwave oven test to verification of the w/c ratio). MnDOT has paid OSU $10,000 for this device. MnDOT will continue to offer a w/c ratio incentive/disincentive. This is intended to be SHADOW Testing.*

$20,000

PEM – QC Plans

- *MnDOT currently requires QC Plans for certain items on concrete paving projects including anchoring dowel bar baskets and cold weather protection plans.*
- *MnDOT Design Build projects currently require a comprehensive QC plan, however I do not think it is as rigorous as is recommended in PP84. We would require a plan as outlined in Section 8 of PP84.*

$20,000

PEM – Control Charting

MnDOT currently charts the following in excel spreadsheets:

- *Air Content (before and after the paver)*
- *Composite Gradations – Job Mix Formulas (moving average of 4 on each sieve, individual composite gradations against the tarantula curve)*
- *Moisture Content (%) and W/C Ratio*

MnDOT would add the following charts for this project:

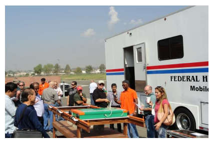
- *Unit Weight (already recorded, just not charted)*
- *SAM Number (we already created a spreadsheet for the SAM testing) – this would be in addition to the Air Content charting*
- *Water Content – already charting*
- *Formation Factor – once it is determined as to what we are measuring, we will create a chart*
- *Strength – we will create a chart to record flexural strength tests*

$20,000

FHWA Mobile Concrete Trailer

Mission

- Technology Transfer to SHA's
  - Field demos on active projects
  - Equipment loan
  - Training of staff
  - Conferences and workshops



MCT – Conventional Tests

- Temperature
- Slump
- Air Content (Type B)
- Strength
  - Compressive
  - Flexural
  - Split Tensile
  - Elastic Modulus and Poisson's ratio

MCT – Non Destructive and In-situ

- Box Test
- Match Curing
- Maturity
- Pull Out Strength
- Pavement Thickness
- Dowel Bar Alignment

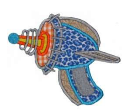
- Tensile Bond Strength
- Ultrasonic Tomography
- Capillary Pressure Sensing
- Handheld Ground Penetrating Radar

MCT – Durability Tests

- Super Air Meter (SAM)
- Surface Resistivity
- Rapid Chloride Permeability
- Calorimetry
- Microwave Water Content
- Coefficient of Thermal Expansion
- HIPERPAVE software
- Aggregate gradation software

Some closing thoughts…

- Further development of performance mix designs will evolve…the exciting thing is technology is getting to the point where we will have tools that can give us better indications of the long term quality of the concrete…



DEPARTMENT OF TRANSPORTATION

Thank you
Questions?

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