Performance Engineered Mixtures (PEM)

For Concrete Pavement

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History

- Concrete Paving Specs have not kept up with innovations in testing technologies.
  - Strength, air and slump
- Mixtures are more complex:
  - Chemical admixture
  - Supplemental cementitious materials
- As well as:
  - Increase in traffic
  - More aggressive winter maintenance
  - Get in and get out as quickly as possible.

History

- Recognizing the need a partnership was formed – April 2015
  - Federal Highway Administration (FHWA)
  - American Concrete Paving Association (ACPA)
  - Portland Cement Association (PCA)
  - Member state of National Concrete Consortium (NCC)

- Formed an Expert Task Group including seven champion states
  - Indiana, Iowa, Minnesota, Michigan, Nebraska, South Dakota, Wisconsin, the Illinois Tollway and Manitoba

AASHTO PP84-17

- Published April 2017
- Identified Properties Controlling Concrete Mixture Performance:
  - Aggregate Stability – including alkali aggregate reaction and D-cracking
  - Fluid Transport Properties – The ability to resist passage of wanted and aggressive fluids
  - Cold Weather – The ability to resist freezing and thawing the effects of deicing salts
  - Shrinkage – As it affects random cracking as well as warping
  - Strength – the ability to carry static, dynamic, and fatigue loads
  - Workability – As it affects the constructability of the system, and the observation that the efforts to overcome poor workability can impact durability

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Aggregate Stability

- **D-cracking:**
  - AASTHO T 161, ASTM C1646
- **Alkali Aggregate Reactivity :**
  - AASHTO R 80

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Transport Properties

- **Water to Cementitious materials (w/cm) ratio:**
  - The required Maximum w/cm ratio is selected based on freeze-thaw conditions
- **Formation Factor: Table 1 (AASHTO PP84)**
  - Based on freeze-thaw conditions (based on resistivity testing)
- **Ionic penetration, F factor: Appendix X2 AASHTO PP 84**
  - Determined using guidance provided in Appendix X2

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Cold Weather

- **Water to Cementitious materials (w/cm) ratio:**
- **Fresh Air Content**
- **Fresh Air Content/ SAM**
- **Time to Critical Saturation (ASTM C1585)**
- **Deicing Salt Damage (30% SCM)**
- **Deicing Salt Damage (AASHTO M 224- topical treatment)**
- **Calcium Oxychloride Limit (AASHTO T 365)**

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Shrinkage

- Reducing unwanted slab warping and cracking due to shrinkage:
  - Volume of paste (25%)
  - Unrestrained volume change – AASHTO T 160
  - Restrained shrinkage – AASHTO T 334
  - Restrained shrinkage – AASHTO TP 363-13
  - Probability of cracking - AASHTO PP 84 (Appendix 1)

Concrete Strength

- **Flexural strength**
  - AASHTO T 97
- **Compressive strength**
  - AASHTO T 22

Workability

- **Traditional acceptance criteria would have been the slump test.**

- **Box test- Appendix X3**
  (AASHTO PP 84)
- **V-Kelly test- AASHTO TP 129**

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Table 3 – Summary

Table 3—Specification Worksheet for Mixture Proportioning

Section	Property	Specified Test	Specified Value		Mixture Qualification	Acceptance	Selection Details	Special Notes
			6.3 Concrete Strength					
6.3.1	Flexural Strength	T 97	4.1 MPa	600 psi	Yes	Yes	Choose either or both	—
6.3.2	Compressive Strength	T 22	27.5 MPa	4000 psi	Yes	Yes		—
			6.4 Reducing Unwanted Slab Warping and Cracking Due to Shrinkage (if cracking is a concern)					
6.4.1.1	Volume of Paste	—	≤25%		Yes	No	Choose only one	—
6.4.1.2	Unrestrained Volume Change	T160	420 με	At 28 days	Yes	No		
6.4.2.1	Unrestrained Volume Change	T160	360, 420, 480 με	At 91 days	Yes	No		—
			6.5 Durability of Hydrated Cement Paste for Freeze–Thaw Durability					
6.5.1.1	Water to Cementitious Ratio	—	0.45	—	Yes	Yes	a	—
6.5.1.2	Fresh Air Content	T 152, T 196, TP 118	5 to 8%	—	Yes	Yes	Choose only one	—
6.5.1.3	Fresh Air Content/SAM	T 152, T 196, TP 118	≥4%; ≤0.20	—	Yes	Yes		—
6.5.2.1	Time of Critical Saturation	ASTM C1585	30	yr	Yes	No	a, b	Variation controlled with mixture proportion observation or *F* factor and porosity measures
6.5.3.1	Deicing Salt Damage	—	30%	SCM	Yes	Yes	Choose only one if concrete will be exposed to deicing salts	Are calcium or magnesium chloride used
6.5.3.2	Deicing Salt Damage	M 224	—	Topical treatment	Yes	Yes		Are calcium or magnesium chloride used; use specified sealers
6.5.4.1	Calcium Oxychloride Limit	T 365	<0.15 g CaOXY/g paste		Yes	No		Are calcium or magnesium chloride used
			6.6 Transport Properties					
6.6.1.1	Water to Cementitious Ratio	—	≤0.45 or ≤0.50	—	Yes	Yes	Choose only one	The required maximum water to cementitious ratio is selected based on freeze–thaw conditions
6.6.1.2	Formation Factor	Table 1	≥500 or ≥1000	—	Yes	Yes		Based on freeze–thaw conditions; other criteria could be selected
6.6.2.1	Ionic Penetration, *F* Factor	Appendix X2	25 mm at 30 yr		Yes, F	Through ρ		Determined using guidance provided in Appendix X2
			6.7 Aggregate Stability					
6.7.1	D Cracking	ASTM C1646, T 161	—	—	Yes	No		Procedure A
6.7.2	Alkali Aggregate Reactivity	R 80	—	—	Yes	No		—
			6.8 Workability					
6.8.1	Box Test	Appendix X3	<6.25 mm, <30% surface void			No		—
6.8.2	Modified VKelly Test	TP 129	15–30 mm/root s			No		—

Notes:

[a] Choose either 6.5.1.1 or 6.5.2.1.

[b] Choose either 6.5.1.2, 6.5.1.3, or 6.5.2.1.

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Other Criteria

- Acceptance requirements
  - Fresh concrete in freeze-thaw environment
    - Air content
  - Hardened concrete
    - Compressive strength
    - Resistivity
  - Others as deemed necessary by SHA

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Other Criteria

- Quality Control
  - Quality Control Plan
    - Description of actions to monitor the quality of materials, processed and final product
    - How QC data will be managed and reported
      - Control charts exhibiting acceptance ranges and control limits
    - Detailed description of actions to be taken when control limits are exceeded
    - Following tests to be included (minimum)
      - Unit weight
      - Air content / SAM number
      - Water Content
      - Saturated F factor
      - Strength

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Pooled Fund

- Transportation Pooled Fund: TPF-5(368)
  - Objective: to focus on the successful deployment of performance engineered mixtures. This will involve building off the foundational work the FHWA and the “PEM Champion States” have done, with emphasis on implementation, education and training, adjusting the specification values to relate accurately to good pavement performance in the field, and continued development of relating early age concrete properties to performance.

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Pilot Projects

- District 11:
- SR 376 in Moon Township, Allegheny County
- 5 miles of full depth reconstruction of 11” pavement on both East and Westbound lanes

- District 12:
- SR 70 in South Huntington Township, Westmorland County
- 3 miles of full depth reconstruction of 14” pavement on both East and Westbound lanes

- Shadow testing was done on both projects.
- Both project were paved by Golden Triangle.

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What is being implemented- mix design

- Tests to evaluate the mix design
  - Rate of flexural strength development to 90 days
  - Rate of compressive strength development to 90 days
  - ASTM C157 – Unrestrained Volume Change
  - Formation factor from resistivity testing
  - Air content – SAM and pressure meter
  - w/cm ratio $\leq$ 0.45
  - Volume of paste

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What is being implemented- field

- Acceptance testing in field (shadow testing)
  - In addition to the usual slump, air content, temperature and w/cm ratio check the following will also be done:
    - SAM
    - Formation factor from resistivity testing
    - Box test

What is being implemented- QC Plan

- QC Plan
  - In addition to the usual requirements of a QC Plan, these test will be implemented (shadow testing)
    - Unit weight
    - SAM
    - Water content (AASHTO T 318)
    - Formation factor from resistivity
    - Box test

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What is being implemented- Control Charts

- Control Charts
  - SAM
  - Air content
  - Unit weight
  - Water content
  - Strength
  - Formation factor from resistivity

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Future

As the SHA's gain experience with the performance of the PEM mixtures, it is expected that specifications will become more performance based and allow for the innovation that is needed to increase performance. The inclusion of performance measures increases the importance of quality control, as the acceptance criteria are predicted on a well designed and executed quality program.

Better test methods and equipment

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