



www.cproadmap.org

July 2017

ROAD MAP TRACK 1

PROJECT TITLE

Performance Engineered
Mixtures for Concrete
Pavements

TECHNICAL WRITERS

Tom Cackler (lead)
Mike Praul, FHWA
Richard Duval, FHWA

EDITOR

Sabrina Shields-Cook

SPONSORS

Federal Highway Administration
National Concrete Consortium

MORE INFORMATION

Dale Harrington
Snyder and Associates, Inc.
(515)964-2020
dharrington@snyder-associates.com

The Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map) is a national research plan developed and jointly implemented by the concrete pavement stakeholder community. Publications and other support services are provided by the Operations Support Group and funded by the Federal Highway Administration.

Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. The July 2017 MAP Brief provides information relevant to Track 1 of the CP Road Map: Materials and Mixes for Concrete Pavements.

This MAP Brief is available at www.cproadmap.org/publications/MAPbriefJuly2017.pdf.

“Moving Advancements into Practice”

MAP Brief July 2017

Best practices and promising technologies that can be used now to enhance concrete paving

**Developing a Quality Assurance Program
for Implementing Performance Engineered
Mixtures for Concrete Pavements**

Introduction

TRB Circular 137 defines Quality Assurance as all those planned and systematic actions necessary to provide confidence that a product or facility will perform satisfactorily in service. The Quality Assurance Program (QAP) for Performance Engineered Mixtures (PEM) for Concrete Pavements represents a system of individual and shared responsibilities that needs to be understood by the agency and contractor. This tech brief is the second of a two part series on PEM specifications and implementation. The April 2017 CP Road Map MAP Brief “Performance Engineered Mixtures (PEM) for Concrete Pavement” presented an overview of the PEM specification requirements. The CP Road Map MAP Brief and the AASHTO standard of practice PP 84-17 give details on the PEM specification requirements. This tech brief will overview QAP requirements specifically related to PEM, which are a subset of the overall QAP requirements for a project.

An overview of the QAP elements related to PEM is shown in Table 1. It consists of those activities the owner agency does as part of their acceptance responsibilities and also those activities that the contractor is responsible for (Quality Control, QC) to ensure the product meets the contract requirements. Table 1 also summarizes the critical mixture performance requirements and implementation options. More detail is provided in the CP Road Map MAP Brief “Performance Engineered Mixtures (PEM) for Concrete Pavements.”

Background

Historically, agencies have relied too much on 28-day strength of a concrete mixture as a quality indicator. The traditional mindset has been that if the 28-day strength meets

the specification requirements, it was “good” concrete; strength was used as a quasi-indicator of durability. The concrete community was hampered by the lack of tests that were both indicators of concrete quality and those that could be done during production so that changes could be detected and corrected as needed while the project was still under construction.

New Tests

Recently, there have been significant advancement in testing technologies that measure engineering properties important for good performance of the concrete pavement. With these scientific advancements, agencies and contractors now have the ability to effectively monitor their production in real-time and adjust as needed to produce the desired level of quality. These new tests, particularly when used in conjunction with a performance specification and QAP, set the stage for significant advancements in pavement performance. Figure 1 (page 4) shows several of the tests used in the PEM Specification: surface resistivity, calorimetry, and Super Air Meter (SAM).

AASHTO PP-84-17 “Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures”

The PEM specification is a leap forward for the concrete community. It incorporates measuring the critical properties identified in Table 1 into a specification framework (Table 2). The premise behind the specification is to target the mix-design testing and acceptance testing towards those tests that are indicative of concrete quality and that will address known failure mechanisms. The specification removes some prescriptive specification elements, such as minimum or

Table 1. Summary of QAP elements for Performance Engineered Mixtures

Quality Assurance Program (QAP) for Performance Engineered Mixtures												
QAP Elements	Agency Acceptance						Contractor Quality Control Plan					
	Qualify contractors & labs and calibrate plants	Qualify personnel	Independent assurance	Dispute resolution	Measure and evaluate the quality of the final product (inspection)		Determine final payment of completed work	Pre-Construction				During Construction
Overview of QAP requirements specific to PEM	Per agency requirements	Per agency requirements	Per agency requirements	Per agency requirements	Mixture qualification	Per agency requirements	*Consistent with agency decision on 6 critical parameters	Per contract specs	Per contract specs	Per contract specs	Per contract specs	Mixture verification
Agency (mixture acceptance) Contractor (mixture design and production)					Evaluate contractor's mixture proportions	Monitor implementation of contractor's QC plan	Air, strength, w/cm or F, %SCM or CaOXY				Submit mixture design for SHA approval	**Monitor early age mixture properties to ensure mixture produced is consistent with design and production process is uniform
*Varies depending on choice of prescriptive or performance options selected												
**Testing targets, frequency, and action limits (minimum QC testing: unit weight, air, w/cm, F, strength)												
Purpose of the 6 Critical Performance Engineered Mixture Properties												
PEM parameters	Aggregate stability	Transport properties	Paste durability	Shrinkage	Strength	Workability						
Purpose of associated tests of requirements	Aggregate durability including alkali-aggregate reactions and D-cracking	Minimize the passage of water and aggressive fluids into the concrete	Resistance to freeze-thaw damage and chemical attack	Reduce moisture warping and cracking	Ensure structural design requirement is obtained	Ensure mixture consolidates with proper operation of paver and holds an edge						
Applicability	Nationally	Nationally	More critical where deicing materials are used and freezing is common	More critical in dry locations	Nationally	Nationally						
Implementation options	Standard aggregate screening tests	Prescriptive or performance	Prescriptive or performance	Prescriptive or performance	Standard concrete strength tests	Box or V-Kelly tests						

Refer to Table 2 for specific AASHTO or ASTM Test and Property Measured

Table 2. Adopted from AASHTO PP 84-17

PP 84-17 Section	Property	Specified test	Specified value		Mixture qualification	Acceptance	Selection details	Special notes
6.3 Concrete strength								
6.3.1	Flexural Strength	T 97		600 psi	Yes	Yes	Choose either or both	—
6.3.2	Compressive Strength	T 22		3500 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	ASTM C157	420 µε	At 28 days	Yes	No		
6.4.2.1	Unrestrained Volume Change	ASTM C157	360, 420, 480 µε	At 91 days	Yes	No		—
6.4.2.2	Restrained Shrinkage	T 334	Crack free	At 180 days	Yes	No		—
6.4.2.3	Restrained Shrinkage	TP 363-17 (Dual Ring)	$\Sigma < 60\% f_r$	At 7 days	Yes	No		
6.4.2.4	Probability of Cracking	Appendix X1	5, 20, 50%	As specified	Yes	No		—
Commentary	Quality Control Check	—	—	—	No	Yes		Variation controlled with mixture proportion observation or F factor and porosity measures
6.5 Durability of hydrated cement paste for freeze-thaw durability								
6.5.1.1	W/Cm Ratio	—	0.45	—	Yes	Yes	Choose Either 6.5.1.1 or 6.5.2.1	—
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% air; ≤0.2	%, psi	Yes	Yes		—
6.5.2.1	Time of Critical Saturation	"Bucket Test" Spec	30	yr	Yes	No	b	Variation controlled with mixture proportion observation or F factor and porosity measures
6.5.3.1	Deicing Salt Damage	—	35%	SCM	Yes	Yes	Choose only one	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 365-17	<0.15 g CaOXY/g paste	Yes	No		Are calcium or magnesium chloride used	
6.6 Transport properties								
6.6.1.1	W/Cm ratio	—	≤0.45 or ≤0.50	—	Yes	Yes	Choose only one	The required maximum w/cm ratio is 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 p		Use guidance in App. X2	
6.7 Aggregate Stability								
6.7.1	D Cracking	T 161, ASTM C1646	—	—	Yes	No		—
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 V-Kelly Test	Appendix X4	15–30 mm/ root s			No		—



Figure 1. Surface resistivity test (top left), calorimetry test (bottom left), Super Air Meter (SAM, right)

maximum cement content, and, instead, allows the contractor to innovate and make economical use of their materials in developing a concrete that meets the service needs.

This performance-type specification also includes required QC operations including testing and tracking the results of a number of tests as part of the approved QC plan. Figure 2 shows an example control chart monitoring unit weight and air content of plant produced concrete. The inclusion of mandatory QC requirements is an acknowledgement of the significance of QC in a performance versus a prescriptive specification. In a prescriptive specification, the agency dictates much of how the product will be produced. In some respects, the contractor does not “own” the process because they did not develop it; since the controls on the process are largely external, the benefits of QC are minimized.

In contrast, a performance specification provides flexibility to the contractor to determine how to meet the contract performance requirements. This not only gives the contractor the ability to economically innovate but shifts much of the control from the agency to the contractor. However, agencies remain accountable for public funds and, therefore, they need to retain some review and approval authority on how the contractor intends to provide a quality product. The QC plan provides a vehicle for the contractor to communicate to the agency how they intend to meet the specification.

In a performance specification environment, the QC plan is a very important document. Agencies should review and approve the document and monitor the QC operations to ensure they are followed. Performance specifications do not solve all potential quality problems that may occur nor do they relieve the agency of its oversight obligations. They do allow for innovation and potentially more economical and better performing concrete in service, but they also require agencies and contractors to change their approach to QC and understand the shift in roles and responsibilities for both the contractor and the agency.

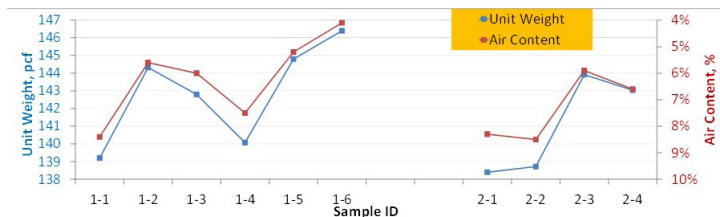
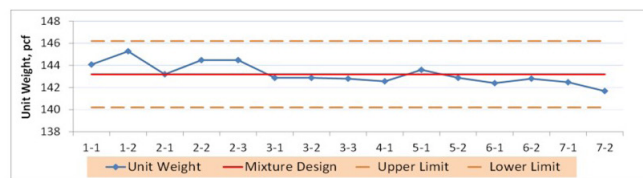


Figure 2. Example of contractor's control chart monitoring unit weight and air content

Translating Design-Build Lessons Learned to All Projects

Over the last decade or so, many agencies have gained experience with design-build (DB) contracting. DB contracting inherently provides a substantial level of control to the contractor, similar to a performance specification on a more typical project. Agencies have responded to this shift in control by requiring detailed QC plans that document how the contractor will ensure a quality product that meets the contract requirements. The QC plan on a DB project contains details on what constituent materials will be used, how they will be produced and monitored, how they will be batched and incorporated into the concrete, and how the concrete quality will be tested and monitored throughout the project. It often contains discussion on how various issues will be responded to should they arise.

This is exactly the approach agencies need to take with a performance specification. Similar to a DB project, control has been shifted from the agency to the contractor. As they have done with DB projects, agencies need to respond to this shift in control with a concurrent increase in QC and QC plan requirements to assure the contract requirements are met and the intent of the specification is satisfied.

Agency Application of the PEM Specification

To successfully implement the PEM specification, the owner agency should recognize that there are important choices they need to make, decisions that the contractor needs to make, and requirements that are best made in collaboration with each other. The goal should be to incorporate specification requirements that can significantly improve pavement performance, without introducing unreasonable risk to either party.

How to get started

The agency will need to select an approach to implementing PEM requirements that meets their local conditions and contracting environment. Agencies with extensive experience specifying and building concrete pavements may choose to begin with choices that will be different than agencies who don't build many concrete pavements and have a limited number of contractors that perform concrete paving.

The PEM requirements have been selected because they are important for pavement performance and each requirement can be measured with currently available testing technologies. The requirements collectively will result in increased reliability that the pavement will achieve the design objectives. However, be aware that some requirements may be less important in certain climatic regions. Table 1 summarized where the PEM requirements may be more applicable and additional detail is provided in the CP Road Map MAP Brief (April 2017): Performance Engineered Mixtures (PEM) for Concrete Pavements.

It is also recommended that agencies set up a mechanism to collaborate with industry on implementing PEM requirements. Each party needs to be aware of the opportunity that PEM specifications represents for improving pavement performance, and a plan needs to be developed that includes education, training, project-level testing, and pilot projects (figure 3). It is recommended that experience be gained on how to meet the PEM requirements before broadly implementing. Technical assistance is available through TPF-5(368) and FHWA's Concrete Pavement Performance System as described later in this MAP Brief (<http://www.pooledfund.org/Details/Study/620>). A well-planned approach may take



Figure 3. Contractors and state highway agency personnel measuring air content using the SAM

time to fully implement, but will result in more buy-in and less risk for all parties.

A note of caution: Frequently with new specification requirements, the tendency is to add them to the existing specification as additional requirements. This should be avoided with PEM as it is likely there will be conflicting mixture requirements that will not be possible to satisfy.

Selecting Performance vs Prescriptive Requirements

For most of the PEM requirements, an agency may choose from a prescriptive or performance approach. The specification was specifically designed this way in order to give the ability to select the approach that will best meet the project needs and experience level of the agency and contractors.

Over time, it is anticipated that most agencies will move to the performance approach for each requirement, as this will allow the contractor to have the greatest opportunity for innovation and resulting cost savings for the agency while meeting the project performance requirements. However, initially, as experience is being gained, an agency may choose some of the prescriptive requirements based upon their experience and project conditions.

Table 2 (derived from the PP 84-17 specification) on page 3 of this document shows the options available for each of the six critical mixture parameters.

In Table 3 (below), an example has been developed to show how a prescriptive or performance approach may be chosen. With either option, it is important that the contractor have a well-designed and executed QC plan, as will be discussed later in more detail.

Table 3. Example PEM acceptance criteria for prescriptive and performance-based approach

Mixture parameter	Most prescriptive approach	Most performance approach	Currently measured
Aggregate Stability	Aggregate stability tests	Aggregate stability tests	Yes
Transport Properties	w/cm ratio	Ionic penetration, F	No
Freeze Thaw Durability	w/cm ration, minimum 35% scms & air using standard pressure meter	Time to critical saturation, SAM & Calcium oxychloride limit	No
Shrinkage	25% volume of paste	Calculate probability of cracking	No
Strength	Flexural or compressive	Flexural or compressive	Yes
Workability	Box or VKelly	Box or VKelly	No

Building Confidence

The agency needs to know that the PEM specification requirements are cost-effective and are resulting in improved pavement performance. The contractor needs to have confidence on how to meet the PEM requirements and how to monitor the production and placement process to deliver the mixture that was approved during mixture qualification by the agency. Risk to both parties needs to be minimized. There are a number of steps that an agency can take to support these objectives.

Education & Training

Education and training for both agency and contractor personnel is critical. This includes management as well as project personnel. It is important for agency management to establish communication with local contractors and develop a process that will result in everyone involved in the PEM process having a good working knowledge of the specification and why it is being adopted.

An early need for project personnel is to provide training on each of the new test procedures and establish a qualification process for ensuring proficiency.

Shadow and Pilot Projects

There is no substitute for experience. Shadow projects, in combination with pilot projects, should be considered as a way of gaining experience with PEM requirements without introducing a lot of risk.

The advantage of this approach is that it lets the contractor gain experience on mixture qualification, mixture production, and process control before getting into a bidding environment. It allows the agency to understand test results on paving concrete and set specification requirements that are both achievable and will address the performance needs of their projects.

Performance Monitoring

The ultimate goal of the PEM specification is to improve the performance of concrete pavements while allowing the contractor to be innovative and reduce production costs. Significant advancements have been made on understanding how fresh concrete properties relate to performance.

However, at the end of the day, monitoring how the projects are performing will be the most important indicator of the success of pavements built with PEM specifications. This will likely do more for building confidence in PEM specifications than anything else. A work task under TPF-5(368) will establish a mechanism for agencies to share project performance experience.

Contractor's Responsibilities for Mixture Production and Quality Control

The need for good quality control (QC) by the supplier/contractor is a generally understood concept. Without proper QC, contractors may face financial disincentives and/or the mandate to remove and replace defective concrete. Also, it allows less qualified contractors to lower their price and many times results in an unsatisfactory product. Owners then suffer the consequences as they are left with a lower-quality product than desired or a delay in completion of the project due to re-work.

For many years, the lack of real-time testing during production, coupled with the widespread use of prescriptive specifications, provided little ability or motivation for industry to develop comprehensive QC processes. As a result, QC often consists solely of doing moisture and gradation testing of aggregates and monitoring 28-day strengths of the mixture. While these activities are needed, and are part of a QC program, they only provide a limited opportunity for contractors to proactively address quality issues on a given project. The PEM specification changes this historical approach and recognizes the critical role of mixture qualification and QC during production in building a successful project.

There are three important responsibilities related to the concrete mixture under the PEM specification: mixture design, mixture qualification, and mixture verification. Table 1 shows how these elements are part of the QAP for a project. Collectively these responsibilities represent a system that ensures the owner agency that the concrete mixture meets the PEM specification requirements and that the contractor has a production process that is in control and produces consistence, quality concrete. The PEM specification requires that the contractor submit a Quality Control Plan (QCP) to the agency for approval prior to beginning work.

Mixture Design

Mixture design consists of choosing the properties of the mixture required to meet engineering needs. Mixture proportioning includes material selection and selection of the amount of these materials to be included in the mixture. Trial mixtures are evaluated in the laboratory to ensure compliance with specification requirements. One or more proposed mixtures and project materials are submitted to the agency for approval.

In addition to the required test results for each of the 6 PEM parameters (aggregate stability, transport properties, paste durability, shrinkage, strength, and workability), additional properties are to be reported, as shown in Table 4.

Figure 4 shows examples of the Box and V-Kelly tests for evaluating workability during mixture design.

Table 4. Properties to report for mixture qualification (from AASHTO PP 84-17)

Property	Test method	Purpose
Rate of flexural strength development to 90 days	T 97	Calibration with compression
Rate of strength development to 90 days	T 22	Calibration with flexural
Coefficient of thermal expansion	T 336	Design check
Unit weight	T 121	Basis for QC monitoring



Figure 4. Box Test (left) and V-Kelly test (right) for evaluating workability of the concrete mixture

Mixture Qualification

The contractor is to submit the mixture design to the agency for approval 30 days before concrete production. The agency is to evaluate the mixture for compliance with the specification requirements. The contractor also needs to submit a QC plan showing how he intends to monitor the field production and placement to ensure that the mixture being produced has the same characteristics as the mixture approved.

Mixture Verification

Mixture verification includes the activities undertaken during production and placement to ensure that the mixture that is produced has the same characteristics as the mixture that was approved. These activities are communicated to the owner agency in the contractor's QCP. The QCP needs to identify testing target values, testing frequency, and action. The PEM specification requires minimum QC testing, as shown in Table 5.

Table 5. Minimum QC testing required by the PEM specification (derived from AASHTO PP 84-17)

Test	Test Method	Frequency	Target	Control Limit
Unit weight	T 121	Weekly	*	*
Air content/ SAM number	T 152, T 196, or TP 118	1000 m2 (1200 yd2) or daily	*	*
Water content	T 318	Daily	*	*
Formation factor	Appendix X2	1000 m2 (1200 yd2) or daily	*	*
Strength	T 97 and/or T 22	1000 m2 (1200 yd2) or daily	*	*

Technical assistance available to SHAs through the FHWA's Concrete Pavement Performance System (CPPS)

FHWA supports the move to performance specifications and, specifically, the implementation of the PEM specification. PEM offers the opportunity to specify new tests at both the mix design approval stage and during concrete production. PEM also requires QC activities by the contractor/supplier, which may not be standard practice in all states. Figure 5 shows an example of FHWA's Mobile Concrete Trailer (MCT) providing hands-on technical training for agency personnel.

Implementing new tests along with concurrent changes to agency oversight and contractor QC processes presents unique challenges. To help address these challenges, FHWA is committed to a series of initiatives as part of their Concrete Pavement Performance System (CPPS). Technical support includes the following:

- A series of one pagers that will serve as a useful and ready reference on the tests considered to be part of an overall performance approach to paving concrete. These one pagers will include a brief discussion of the test, what it measures and why, suggestions on how to incorporate the test into acceptance and QC programs, and suggested frequencies for performing the test. Additional guidance will be provided on the use of test results, such as: (1) Does the test lend itself to a percent within limits (PWL) acceptance process versus a single test pass/fail result and (2) Do the results lend themselves to control charting as part of a QC program?
- Tests envisioned being included are as follows (*indicates tests that are specifically included in PEM):
 - Super Air Meter*
 - Surface Resistivity*
 - Maturity
 - V-Kelly*
 - Smoothness
 - Unit weight*
 - MIT Scan
 - Microwave water content*
 - Formation factor*
 - Calorimetry
 - Compressive/flexural strength*
 - MIT scan T2
 - Box test*
 - Coefficient of thermal expansion*



Figure 5. Photo of FHWA's Mobile Concrete Trailer providing hands-on technical training on PEM testing procedures

- Videos to accompany each test. These videos will demonstrate the test being performed, will include narration, and will be appropriate for technician training.
- QC Plan template that conforms to the PEM requirements.

These efforts will support FHWA's longer-term goal of building on PEM and developing an entire performance specification for concrete, including the construction process and testing hardened concrete. FHWA is currently working with states, industry, and academia to move these initiatives forward to improve concrete processes and practices.

Future of PEM and Performance Related Specifications

As progress is made with implementing PEM, it is natural to consider the future, which will evolve to the development of Performance Related Specifications (PRS). PRS falls along the quality assurance (QA) continuum, basing acceptance on materials and construction quality characteristics that are amenable to acceptance testing at the time of construction and that are corrected to field performance over the life of the structure. In sum, PRS ties together field construction and the PEM specification, which establishes concrete mixture properties.

Some of the CPPS tests shown above may be incorporated into the agency acceptance process. When that happens, tests are performed based on random, statistical sampling on each constructed lot within a project. In PRS, incentives and disincentives are awarded to the contractor for that lot based on performance prediction modeling of long-term economic benefits. As compared to other QA specifications, such as PWL, PRS provides a direct and improved linkage between design, materials, specifications, and construction.

Performance Related Specifications transfer some of the performance risk from the agency to the contractor in return for allowing the contractor to be more innovative and more competitive while targeting PRS-related incentives. This will result in higher quality concrete and more efficient construction practices, reducing long-term costs to the agency.

The key to realistically implementing PRS is to understand the relationship between the acceptance test results and performance of the pavement. Over the next few years under the TPF-5(368) study on Performance Engineered Concrete Paving Mixtures which will begin in the summer of 2017, a national database will be developed to capture these relationships. This information will be used to refine the recommended test limits in the AASHTO standard of practice PP-84 and will enable agencies and industry to better understand how early age concrete properties will relate to long term field performance of the pavement.

Conclusion

Recent scientific advancements, combined with the public sector move towards performance specifications, present a unique opportunity to move concrete technology forward. In order to move in this direction, agencies and contractors must work together and modernize long-standing business practices and assess them in the context of a performance specification. Upgrading QC practices, by both agencies and industry, will be a key part of the success of performance specifications.

Implementation of PEM specification and QAP requirements needs to be supported by education and training so that both parties to the contract understand how to meet the requirements without introducing undue risk to either party. Over the next few years, field experience and performance monitoring of projects built under PEM requirements will enable agencies to set testing limits that will significantly improve pavement performance. Verifying these relationships by monitoring field performance will give both agencies and contractors confidence in moving towards the performance options within the PEM specification.

Implementation support and establishing a national database of performance experience is provided under the TPF-5(368) project: Performance Engineered Concrete Paving Mixtures. Agencies are encouraged to consider participation in this project.

Acknowledgments

The authors would like to acknowledge and thank AASHTO, FHWA, state highway agencies, ACPA, PCA, RMC Foundation, and local industry representatives for their technical and financial support to implement PEM specifications.

References

- American Association of State Highway and Transportation Officials (AASHTO). 2017. "Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures." PP-84-17: Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures.
- Cackler, T., Harrington, D., Taylor, P.C., et al. 2017. "CP Road Map MAP Brief (April 2017): Performance Engineered Mixtures (PEM) for Concrete Pavements." Iowa State University, Ames, Iowa.
- Fick, G., Taylor, P., Christman, R., and Ruiz, J.M. 2012. "FHWA-HIF-13-059 Field Reference Manual for Quality Concrete Pavements." FHWA-HIF-13-059.
- FHWA TPF-5(368): Performance Engineered Concrete Paving Mixtures
- Transportation Research Board of the National Academies. 2009. Glossary of Highway Quality Assurance Terms, fourth update. TRB Circular E-C 137.