

# New Tests and Field Observations in the Material and Construction Optimization Project

National Concrete Pavement  
Technology Center



tech transfer summary

## PROJECT NUMBER

FHWA Pooled Fund Study TPF-5(066)

## PRINCIPAL INVESTIGATOR

Jim Grove, P.E.  
PCC Paving Engineer, CP Tech Center  
Iowa State University

## SPONSORS

Federal Highway Administration  
American Concrete Pavement Association  
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[www.cptechcenter.org](http://www.cptechcenter.org)

CP Tech Center  
Iowa State University  
2901 South Loop Drive, Suite 3100  
Ames, IA 50010-8634  
515-294-3230

The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.

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## Problem Statement

The chemistry of today's concrete mixture designs is complicated by many variables, including multiple sources of aggregate and cements and a plethora of sometimes incompatible mineral and chemical admixtures. Adding to the complexity are construction variables such as weather, mix delivery times, finishing practices, and pavement opening schedules.

Mixture materials, mix design, and pavement construction are not isolated steps in the concrete paving process. Each affects and is affected by the other in ways that determine overall pavement quality and long-term performance.

Equipment and procedures commonly used to test concrete materials and concrete pavements have not changed in decades, leaving serious gaps in our ability to understand and control the factors that determine concrete durability. The concrete paving community needs tests that will adequately characterize the materials, predict interactions, and monitor the properties of the concrete.

## Objectives

The Material and Construction Optimization for Prevention of Premature Pavement Distress in PCC Pavements (MCO) project was initiated to investigate available and new testing procedures for evaluating concrete materials, mix designs, and construction practices.

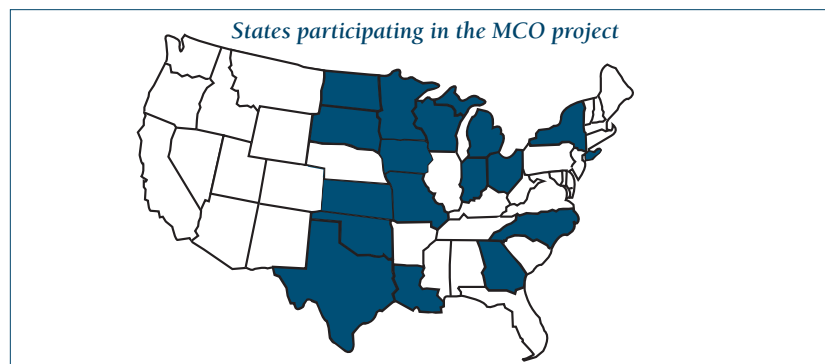
Objectives include the following:

- Evaluate conventional and new technologies and procedures for testing concrete and concrete materials to prevent material and construction problems that could lead to premature concrete pavement distress.
- Examine and refine a suite of tests used to more accurately evaluate concrete pavement properties.

## Project Partnerships

The MCO project is sponsored through a pooled fund partnership that includes the FHWA, 16 state departments of transportation, and the concrete paving industry. The Iowa DOT serves as the lead state for the project.

The National Center for Concrete Pavement Technology (CP Tech Center, previously known as the PCC Center) at Iowa State University is responsible for the management and execution of the research. A technical advisory committee composed of representatives from participating states, industry, and the FHWA provides technical direction and guidance to the project.



## The Tests

A summary of selected test procedures is provided below, including objective findings based on data collected to date and subjective observations of the research team based on their experiences implementing these test procedures in the field.

### Heat Evolution Quick Test (Coffee Cup Test)

An insulated container is used to determine the early stiffening of cement and fly ash in the heat evolution quick test, or coffee cup test. Coffee cup testing has been challenging to implement in the field. The research team has modified this procedure numerous times in an effort to develop a test that can be performed in a timely manner with repeatable results. As of March 2006, it appears that the current version of the coffee cup test can be performed in approximately 45 minutes of obtaining a sample. The sample must be stabilized at  $70^{\circ}\text{F} \pm 3^{\circ}\text{F}$  before testing. This test shows promise of providing information to the contractor and agency about changes in cementitious materials. Troubleshooting poorly performing mixes can be simplified by knowing that the cementitious materials have changed. Based on limited results from the first two field demonstration projects of 2006, the revised coffee cup test procedure appears to be repeatable and should be strongly considered for use as a quality control test procedure.

### Flow Table Test

The flow table test (modified from ASTM C 1437 and the Dan Johnston method) is used to determine the early stiffening of mortar. The research team has successfully adapted the test to field conditions. The goal is to determine the concrete properties that can be identified through the test results. Mortar flow may be an indication of water/cementitious ratio and workability/placeability properties. One observation of the research team is that the flow test has more resolution than the slump test. Mixes that have had consistent slump measurements do exhibit slight variation in flow measurements. This variation may indicate slight changes in workability that the slump test does not show, or it may be a function of the mortar sampling method. At this time, the research team would propose that mortar flow testing be included as an optional test procedure for all project phases (mix design, preconstruction mix verification, and construction quality control).



Flow table device

### Heat Signature Test

Heat signature (calorimetry) testing has the potential to provide important feedback regarding material changes and strength gain properties in the field. Beginning in April 2006, the research team will be evaluating an alternative method of collecting data. In addition to the IQ drum method, two maturity sensors will be embedded in the concrete sample. One of the sensors will record the temperature of the sample at fifteen-minute intervals, and the other sensor will be programmed to measure the temperature of the sample at three-minute intervals. The data obtained from the sensor that is recording at three-minute intervals will be analyzed to determine if initial set and final set can be identified. The majority of mixes tested to date have had peak temperatures within 36 hours. Further analysis and research are needed to determine the duration of this test for field quality control purposes. Once a library of heat signature curves has been collected and categorized regarding workability/placeability, new curves can be compared to past results in an effort to identify workability issues before they occur in the field. Heat signature testing should be implemented for the mix design and mix verification stage. Further evaluation and/or a revised test procedure are needed to fully implement heat signature testing as a field quality control test.

### Gradation Testing

Sieve analysis data have been collected from contractor and agency test results. These data have been used to calculate and graph coarseness factor, workability factor, percent passing, and the combined percent retained on individual sieves. Practical considerations for implementing combined grading analysis in the field include utilizing belt samples or approved stockpiles that have multiple test results for each stockpile. If approved stockpiles are used, the coarsest and finest samples from each stockpile should be mathematically combined to evaluate the potential range of combined grading that can be produced from those specific stockpiles. From observations of the paving process of all field demonstration projects to date, a subjective conclusion could be made that dense graded mixes require less effort to place and finish. Combined grading should be implemented at all project stages to evaluate potential placement issues and as a measure of consistency during production.

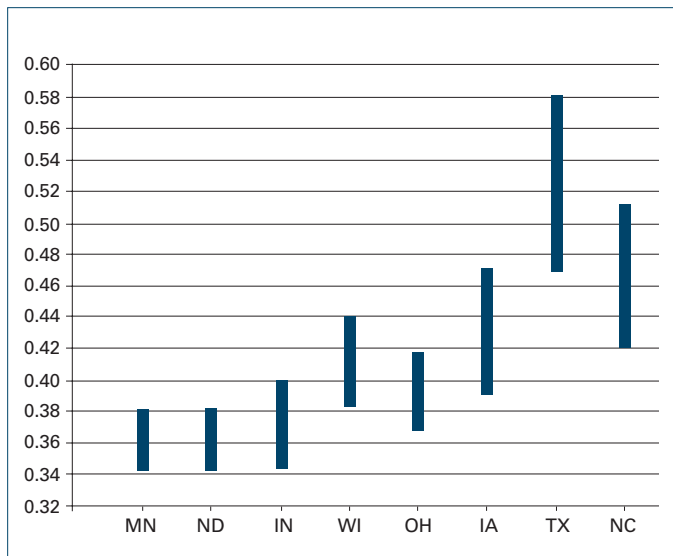
### Set Time Testing

Set time testing has been conducted for a majority of the field demonstration projects. Mortar samples are obtained by wet sieving the concrete mixture using a vibrating cylindrical apparatus (squirrel cage) that was developed by the project team. An adequate volume of mortar normally can be obtained in less than 10 minutes. Using field samples of production concrete for this test procedure introduces variability in the sample temperature that is not a factor when performing this test in a standard laboratory environment. After sampling, the test is conducted in the mobile lab under normal conditions. At this time, the research team would propose that this test be conducted during the mix design stage under lab conditions and potentially once in the field during the mix verification stage. The field test should be conducted in conjunction with a heat signature test.

### Microwave Water Content Test

Water/cement ratio is easily performed in the field using the microwave water content test. Based on observations of the research team, the water/cement ratio obtained in this manner is an excellent measure of mix consistency. It appears that mix consistency can be controlled by contractors paying closer attention to the aggregate moisture compensation values used by the plant computer. This observation is supported by the data shown in the graph.

Note that both Minnesota and North Dakota have a specification requirement for performing this test. Microwave water content testing should be implemented for all project stages.



Water/cement ratio determined by microwave  
(sorted by standard deviation)

### Maturity Testing

Concrete maturity testing is a proven technology for estimating in-place strength for opening to traffic decisions. Strength-maturity relationships have been developed for all projects except two. The project team has used the field demonstration projects as an opportunity to demonstrate the implementation of the maturity method on a paving project. It is recommended that maturity testing should be implemented for all projects to nondestructively determine the strength of the pavement. The strength-maturity relationship should be developed during the mix verification stage in the field as paving begins. At least one maturity sensor should be placed near the end of a day's paving for opening to traffic decisions.

### Air Void Analyzer (AVA) Test

The mobile lab's air void analyzer (AVA) with isolation base provides an important new method of measuring the volume, size, and distribution of air voids in concrete in the field. With this information, quality control adjustments in concrete batching can be made in real time to improve the air void system and thus increase freeze-thaw durability.

The key factor in utilizing the AVA in a mobile lab environment is to isolate the AVA from the vibrations of the trailer. The AVA is a sensitive machine that has been considered accurate only in buildings, thus limiting its use in field control. Because vibrations, such as those caused by wind, can dramatically skew the AVA's results, the trailer was designed with a portal in the floor to accommodate the AVA. When the lab is parked, the base of the AVA rests on the ground through the hole and is surrounded by a weather shield so that it is protected but not touching the trailer.

Overall, the AVA has been reliable; the most common problem that the technicians have experienced with the AVA has been a failure of the mortar sample to break up; this appears to occur with samples obtained from dense-graded low-slump concrete (<math><1''</math>) or samples that are over 2 hours old. Preliminary analysis of AVA test results does not show a consistent relationship between on-vibrator and between-vibrator samples. Additionally, a reliable relationship between AVA results and hardened air samples cannot be determined.

Over the course of the 2006 field demonstration projects, the research team is also obtaining AVA samples in front of the paver. These samples are being used to evaluate the shelf life of AVA samples and to determine whether there is a discernable difference between entrained air properties in front of the paver versus those behind the paver. Implementing AVA testing on a full scale may be easier if samples can be obtained in front of the paver.

Further research is needed regarding the repeatability and reproducibility of the AVA before strict acceptance/rejection limits can be established. Despite the variability within sample results, the research team advocates the use of the AVA in the field. The AVA is the only tool currently available that provides the contractor and agency any information about the pavement's entrained air properties within an hour of placement. This timely feedback is invaluable for avoiding continued placement of concrete pavement with insufficient entrained air and makes the test a true process control tool.



AVA operation

### Vibration Monitoring

Observation and recording of vibrator frequency by manual methods is difficult to implement. Safety issues must be considered while obtaining these measurements. Additionally, the research team questions whether a representative and/or accurate measurement can be obtained with manual sampling methods. It is suggested that automatic vibrator monitors should be used whenever feasible. This provides ongoing monitoring of the vibrator frequencies and gives a warning if the frequencies exceed or fall below set limits. Further research is needed to quantify the relationships between vibrator frequency, vibrator amplitude, paver speed, and combined grading of the mix.

### HIPERPAV Analysis

HIPERPAV software has been used on field demonstration projects to demonstrate its usefulness to the construction process, particularly for avoiding early cracking issues. Obtaining reliable inputs for subgrade and subbase support values can potentially be a barrier to implementation of HIPERPAV. Seventy-two hour forecast weather data are available from the National Oceanic and Atmospheric Administration's website ([www.weather.gov](http://www.weather.gov)). These data can be downloaded into a spreadsheet and easily copied into HIPERPAV. Further development of HIPERPAV should include the capability to perform stress versus strength analyses for an entire day of paving and the capability to input minimum and maximum values for input variables. HIPERPAV should be implemented during the quality control stage of projects.

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## Phase I (2003–2004)

### State Data Collection

As part of Phase I, the MCO project research team contacted and visited each participating state to gather information related to concrete and concrete material tests. Three types of information were gathered: (1) state research, (2) state practices and procedures, and (3) problem projects.

### Preliminary Suite of Tests

From this information, a preliminary suite of tests to ensure long-term pavement performance was developed. The goal was to include tests that provide useful information and results that are easy to interpret and that can be reasonably performed routinely in terms of time, expertise, training, and cost.

The tests examine concrete pavement properties in five focal areas determined to be most critical to the long life and durability of concrete pavements: (1) workability, (2) strength development, (3) air system, (4) permeability, and (5) shrinkage. For each of these areas, tests were identified as existent and adequate, existent but needing further development, or nonexistent and needing to be developed. The tests were considered for relevance at three stages in the concrete paving process: mix design, preconstruction verification, and construction quality control.

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## Phase II (2004–2006)

### Field Demonstration Projects

As part of Phase II, the research team is currently conducting field visits to an active project in each participating state to evaluate the preliminary suite of tests and demonstrate the testing technologies and procedures using actual project materials under actual field conditions.

The field testing conducted from August 2004 through March 2006 included 12 state demonstration projects. The evaluation of the results of these projects has helped identify a number of tests that have given promising results to date. Four final state demonstration projects will be performed in 2006 and will help complete the field evaluation of the proposed tests.

### Mobile Concrete Research Lab

A 44-foot-long trailer was custom designed and equipped as a state-of-the-art mobile concrete testing laboratory to facilitate the field demonstration projects. Funding for the Mobile Concrete Research Lab was provided by the American Concrete Paving Association, state/regional concrete paving associations, and Iowa State University.

The lab includes

- Air void analyzer (AVA)
- Weather station

- Wireless computer with global position system (GPS) and data analysis software
- Sieves stored in custom-built cabinets to determine coarse and fine aggregate gradations
- Microwave oven to determine water-to-cement (w/c) ratios
- Penetrometer to test mortar set time
- Core drill and concrete saw
- Curing tank
- Calorimeters (heat signature drums) to determine the heat signature of mortar and concrete
- 250,000 lb capacity compression tester to measure compressive and flexural strength development

The lab records detailed weather data and GPS coordinates from the beginning of testing at a project site until the testing is complete. This information will greatly increase the accuracy and meaningfulness of the test data and analysis produced by the project.

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## Phase III (2006–2007)

### Integrating Materials and Construction Practices Manual

In conjunction with the project, a user-friendly field manual of practical tests and troubleshooting guidance was developed. The Integrating Materials and Construction Practices Manual will be available in summer 2006. This field-oriented practices manual will incorporate the current state of practice of concrete material testing and concrete pavement construction. A national training program based on the manual is being developed.

### Final Suite of Tests

Phase III will refine and finalize lab and field tests based on demonstration project test data to improve on our knowledge and practices. This phase will include development of the final proposed suite of tests and guidelines for their use, including a detailed step-by-step procedure for the use of the AVA and a standard test procedure for the coffee cup test.

### Technology Transfer

Project findings and recommendations will be communicated through numerous mechanisms:

- Project website, [www.cptechcenter.org](http://www.cptechcenter.org)
- Interim reports and status reports
- State field testing reports
- Education/training modules
- Presentations and videos
- Final report and summaries

The final suite of tests and training modules, expected to be finalized in June 2007, will communicate the best material and construction practices and research results to practicing engineers, technicians, quality assurance/quality control personnel, contractor superintendents, trade persons, and producers.

