Super Air Meter (SAM) STIC Implementation Initiative
Final Report

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Description of Project:

The Super Air Meter (SAM) is a device developed by researchers at Oklahoma State University (OSU), which is intended to take field testing of fresh Portland cement concrete (PCC) to the next level. Unlike today's standard ASTM C231 Type B pressure air meter (which measures and reports the total volume of air in the fresh concrete mixture), the SAM takes it a step further by reporting not only the conventional total volume of air, but also provides a statistical representation of the overall quality of the air-void system through a SAM Number.

Entraining a quality air-void system of tiny semi-microscopic air bubbles into the fresh PCC is crucial in climatic regions where cyclic freezing and thawing is prevalent. In addition to measuring the total volume of air, The SAM also generates additional output, referred to as a SAM Number, which represents the quality of the air-void system. With this information, the owner can gain a higher level of confidence that their concrete will have the necessary hardened properties to withstand the potentially destructive internal pressures as the water within the concrete matrix begins to freeze and expand. The consequences for not entraining a quality air-void system could ultimately manifest itself in terms of poor freeze-thaw protection, thus reduced service life.

The Michigan Department of Transportation (MDOT) has been exploring the feasibility of adopting the SAM for field testing of fresh PCC for the past several years through active participation in multi-state DOT consortiums and on-going pooled-fund research projects. To date, the SAM is showing national interest amongst several participating state DOT's with respect to its potential role as an advanced field-testing device for quality control QC) and quality acceptance (QA).

MDOT's Experience with the SAM Prior to the STIC

In 2014, MDOT (along with 17 other state DOTs) signed on as an active participant in the transportation pooled-fund study titled *"Improving Specifications to Resist Frost Damage in Modern Concrete Mixtures"* (TPF-5(297)). The principle investigator for the study was Dr. Tyler Ley of Oklahoma State University (OSU) with the lead state agency being the Oklahoma DOT. Shortly after authorization of this pooled-fund study, the consortium of participating state DOTs and the Federal Highway Administration (FHWA) agreed that it would make sense for the National Concrete Consortium (NCC) to include SAM oversight as part of their focus. This is because the 18 pooled-fund participating state DOTs, (along with 13 additional non-pooled-fund participating state DOTs) are active members in the NCC via a separate long-standing pooled-fund project titled *"Technology Transfer Concrete Consortium, TTCC"* (TPF-5(467)). The TTCC has long been the mechanism that facilitated state DOT engagement with the NCC.

The primary focus of TPF-5(297) was to provide state DOTs the opportunity to steer the development and implementation of the SAM. Each state DOT was provided two SAMs with the premise that they would collect concrete field test data from actual highway construction projects. The field usage and data generated would not only challenge the ruggedness of the device but would also be used to assist the researchers toward potentially developing the necessary precision and bias statements for future AASHTO Provisional Standards inclusion. As a result, an AASHTO Provisional Standard for the SAM was developed and successfully balloted for publication by the AASHTO Committee on Materials and Pavements (COMP) in 2017.

Additionally, the SAM is currently being included as part of a broad suite of proposed test methods through another transportation pooled-fund study focused on long-range development of AASHTO specifications, test methods and guidance documents for tomorrow's *"Performance Engineered Mixes (PEM) for Concrete Pavements"* (TPF-5-(368)). MDOT has been a key participant on the FHWA-sponsored PEM leadership team for this study, which has been steering the PEM initiative along with 18 other state DOTs over the course of the past few years.

As discussed above, MDOT continues to be involved in SAM development through several FHWA-sponsored initiatives. The multi-state pooled-fund efforts described above are continuing to evaluate the field data in efforts to gain traction in terms of where the SAM may be employed relative to concrete quality assurance.

STIC Activities

MDOT purchased 17 SAMs using STIC funds with the goal to distribute at least one SAM to each of the seven MDOT Regions showing interest in trying out the device on active concrete projects. The SAMs were assigned to each participating Region via their respective Materials Supervisor with the initial intent being to familiarize the Region materials staff with the device. A few Region field staff seized the opportunity. Prior to commencement of the 2017 construction season, MDOT Construction Field Services (CFS) staff worked with selected Region materials staff in efforts to provide instruction on the use of the SAM. Data and constructive operator feedback relative to MDOT's use of the SAM were then shared with the researcher at OSU, as well as the PEM technical committee in efforts to refine the pooled-fund project direction.

MDOT incorporated the *"Special Provision for Durability Based Field Testing"* into two long-life concrete pavement reconstruction projects as part of the Department's *"Roads Innovation Task Force (RITF)".* Side-by-side shadow testing using the SAM was required as part of the quality control (QC) and quality acceptance (QA) protocol for all mainline concrete paving for the projects. Prior to concrete paving on these two RITF projects in 2018, collaboration between MDOT and the Michigan Concrete Association (MCA) arranged for Dr. Tyler Ley of OSU to travel to Michigan on two occasions to provide day-long training sessions for the QC and QA project staff. The feedback received from all associated parties was outstanding. The SAM field test data along with accompanying MDOT laboratory hardened concrete air-void analyses reports for these two projects were provided to both Dr. Ley at OSU and Robert Conway at the FHWA Resource Center for their national interest and analysis.

In anticipation of future SAM field testing prospects, the MCA and MDOT utilized Dr. Ley's day-long training initiative as a "train-the-trainer" platform to develop a Michigan-based SAM certification course. This course will be offered to interested parties as an additional certification for the current MCA concrete field-testing technician training and certification program. To date, the MCA has conducted four additional Michigan-based SAM certification sessions. Because of the relatively high costs for each SAM, our private sector partners are quite reluctant to invest in the SAM until such a time when it is adopted by MDOT. Hence, as part of current and future training and outreach to the industry, the SAMs purchased as part of this STIC will be used for the hands-on laboratory portion of each MCA training/certification session.

In addition to the field testing conducted under the authority of the RITF, a separate shadow pilot special provision was developed to collect SAM field testing data in 2019 for the multi-year concrete pavement reconstruction project on I-75 in Monroe County. SAM training for both the QC and QA staff was provided by the MCA. Again, these data were provided to OSU and the FHWA for their inclusion into the Michigan SAM database. Additional SAM field testing data will be attained for the next stage of concrete pavement reconstruction in 2020.

The shadow pilot special provision is also included in an upcoming Alternative Pavement Bid (APB) project on I-496 in Lansing, scheduled for the 2020 construction season. Additional projects are under consideration for future SAM shadow pilot data collection and outreach.

STIC Expenditures

Table 1 shows the expenditures for this project relative to the authorized funding of $90,000 (Federal - $72,000, State - $18,000). The project stayed within budget with a minor amount ($1,970.28) in surplus. The project expenditures included acquisition of equipment, development of SAM tester training and certification, and hours allocated by MDOT CFS technical staff for field support, outreach, and specification development.

Table 1. STIC Expenditures

Item	Quantity/Hours	Unit	Item Total
Budget	(Fed: $72,000/State: $18,000)		$90,000.00
CFS Staff	315.5	hours	$31,266.35
SAM Training 1 (RITF)	1	day	$2,345.02
SAM Training 2 (RITF	1	day	$2,320.35
SAM Training 3 (I-75)	1	day	$3,000.00
Equipment (SAMs)	3	$2,898.00 ea.	$8,694.00
	3	$2,854.00 ea.	$8,562.00
	3	$2,854.00 ea.	$8,562.00
	8	$2,910,00 ea.	$23,280.00
Total			$88,029.72
Remaining			$1,970.28

How the Work Specifically Meets the Program Criteria

The work completed under this project provided the opportunity for the Michigan concrete paving construction community to be introduced to the SAM. This outreach is essential in efforts to share the technology with the focus toward implementation. Also, the SAM shadow pilot projects allowed MDOT to collect a significant amount of Michigan-based field data. It is anticipated that this Michigan-based data will be used to (1) corroborate with other pooled-fund participating state DOTs, (2) provide clarity and direction relative to if/how the SAM may be implemented in Michigan, and (3) establish a platform for local calibration of SAM quality thresholds.

Benefits of the Project

The overall benefit of this project was that it provided hands-on outreach and exposure to MDOT Region field staff, consultants, contractors, and concrete producers/suppliers. In addition, the outreach through various venues helped to provide the concrete community with an enhanced understanding of the quality aspects of concrete and the importance of a well-established entrained air-void system in terms of providing internal frost protection for concrete in wet-freeze climates.

Challenges

Granted, the focus of the STIC program is to provide a mechanism for implementation of new technologies. However, it was understood amongst the state DOTs currently participating in the various pooled-fund projects (described earlier in this report) that there are still concerns to be addressed by the SAM research team, of which may be significant from the users perspective, as the SAM makes its way toward national acceptance.

There are considerable concerns throughout the concrete construction industry relative to the accuracy of test results, as well as how the SAM may be implemented into the MDOT concrete quality assurance program. These concerns are valid in that while the MDOT STIC team continues to engage in outreach and exploration of avenues for potential implementation, the testing equipment, test procedures, and thresholds for acceptable quality levels (SAM Number) appears to be continually changing. This is generating angst throughout the concrete construction industry, which is tending to set back stakeholder buy-in. These concerns were shared with the national researchers in efforts to maintain constructive cadence. As a result, progress is being made toward rectifying these outstanding issues in efforts to regain a foothold on progress toward possible future implementation of the SAM.

Lessons Learned

The STIC program is intended to be used as a funding resource for implementation of technologies that have been thoroughly evaluated and are "street ready". Although the SAM showed potential as a device which is intended to take field testing of fresh Portland cement concrete (PCC) to the next level, it was quite evident that there were still outstanding questions and concerns at the time of STIC application relative to its street-worthiness as a standard test method for concrete. Granted, the concept behind the SAM is based on a legitimate technical foundation, which was substantiated by exhaustive laboratory test data. However, the proclaimed thresholds for acceptability have yet to be agreed amongst major stakeholders. Through the several pooled-fund efforts discussed earlier in this report, MDOT was able gain enough confidence in the SAM to lend it credible as a tool to be housed in the MDOT concrete quality assurance toolbox. However, concerns raised by the Michigan concrete construction industry challenge the researchers claim that the SAM is ready for field acceptance. Their concerns are based on uncertainty as to (1) whether a typical operator can consistently conduct a proper test, and (2) whether the repeatability of two tests properly conducted by different operators on the same sample is representative of the concrete's quality and, further, sufficient as a basis of acceptance for payment.

Potential Implementation of the SAM

Taking into consideration the concerns raised by industry, potential incorporation of the SAM into a typical DOT concrete quality assurance program could be employed, as follows:

1. Recognizing that the SAM is a new test method, it would be prudent to limit initial implementation to major trunkline concrete paving projects where concrete mixture variability is minimal.

2. *Testing During Concrete Mixture Development in the Laboratory.* The SAM could be introduced as a mix qualification and verification instrument to be employed as part of the contractor's laboratory concrete mixture development process. The basis for SAM testing of the laboratory trial batch would be to validate the compatibility of the mixture ingredients and that a quality air-void system is achievable. The threshold for initial acceptability of the job mix formula (JMF) could be based on the SAM Number for the fresh laboratory trial batch mixture, not to exceed 0.20.

3. *Initial Startup Testing in the Field.* Since the SAM does not currently have the capabilities of producing an automated printout of the test results, there is currently no way for MDOT to validate the reported SAM number from the contractor's laboratory trial batch. In order to demonstrate the worthwhileness of the SAM for practical application in today's quality assurance environment, the MDOT field inspector should be provided the opportunity to witness and validate the contractor's SAM test result of the approved JMF at initial startup of concrete field production. The SAM Number at startup could then represent the target QC value moving forward for that specific JMF. Additionally, the MDOT field inspector should also conduct a side-by-side SAM test on a split sample used for initial QC startup. The first pressurization cycle of the SAM procedure reports the total air content of the concrete specimen, which could be used to validate correlation between the QC and QA testing equipment and operators.

4. *Concrete Testing During Production Paving in the Field.* During normal daily paving production, the SAM could be used as part of the contractor's routine QC process. Granted, the current MDOT specification requirements state that QC and QA sampling must be independent of each other. However, it may be worthwhile at this early stage of SAM implementation to require random QA testing alongside QC using the same sampling of concrete. The intent would be to introduce the SAM into to the contractor's QC

operations while also collecting data for further analysis. The SAM-based action and suspension limits could be based on what is recommended from the analysis of actual project data collected from MDOT shadow and pilot projects discussed earlier in this report, as follows: Action Limit – 0.30; Suspension Limit – 0.33. These limits could be part of the contractor's QC process control, thus requiring their proactive response when exceeded.

5. *Future Quality Acceptance.* The final objective could be to incorporate the SAM into the MDOT quality assurance program for both contractor quality control, as well as agency quality acceptance for which a basis of payment could be administered.

   Currently, quality acceptance price adjustments for in-place concrete pavement are based on Percent-Within-Limits (PWL) methodology using the field measured total air content of the fresh concrete (ASTM C231) along with the accompanying 28-day compressive strength. These two quality index parameters determine the overall pay factor for each production lot of concrete pavement. The air content of the fresh concrete was selected as a PWL pay factor because of the role that air entrainment plays in terms of frost protection for the concrete in wet-freeze environments.

   The concrete paving industry has recently expressed their reservations regarding implementation of the SAM as an acceptance metric without first engaging in a complete and comprehensive analysis of the Michigan-based SAM data set. The FHWA MI Division office and the FHWA Resource Center have each offered to assist MDOT toward developing the necessary analytical rationale.

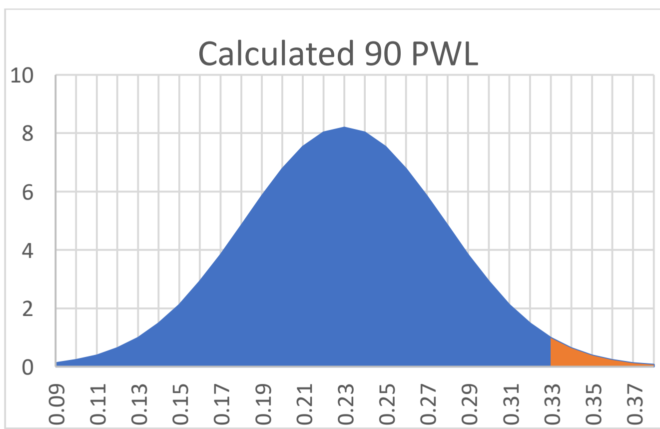

Figure 1. Normal Distribution of Michigan SAM Test Data

   To date, analysis of MDOT SAM field test data (shown in Figure 1) indicate that a reasonable acceptable quality limit (AQL) of 90 PWL correlates with a SAM Number of 0.33. In the first phase of implementation, MDOT could replace the current total air content-based PWL analysis with the SAM-based PWL analysis. The QC action and suspension limit requirements could remain at those currently specified for total air content using the standard Type B meter (ASTM C231). The pay factor and price adjustment analysis for the production lot could then be based on the quality index analysis of SAM Numbers generated from each sublot. In the second phase of implementation, MDOT could discontinue the use of the Type B meter in its entirety, recognizing SAM Number threshold requirements for QC action and suspension limits along with the Sam-based PWL analysis for pay factor determination and price adjustment, as discussed above. MDOT would continue to collect SAM field data in efforts to provide ongoing calibration of the PWL formulae.