Fresh Air Content Test Methods and Analysis of Hardened Air Content in Wisconsin Pavements

Research Objectives

- Determine if disparities in air content exist between use of synthetic and neutralized vinsol resin (NVR) air entraining admixtures (AEA)
- If disparities exist, determine their causes
- Establish reliable methods for testing air void contents in fresh concrete

Research Benefits

- Determined synthetic AEA bubbles are thinner, less robust, less stiff and less likely to survive concrete manipulation than NVR AEAs
- Developed protocols to measure stiffness and thickness of air-bubble shells and for quantifying stability of AEA foams

Principal Investigator

Steven Cramer
University of Wisconsin-Madison
cramer@engr.wisc.edu

Project Manager

Kevin McMullen
Wisconsin Concrete Pavement Assoc.
kmcmullen@wisconcrete.org

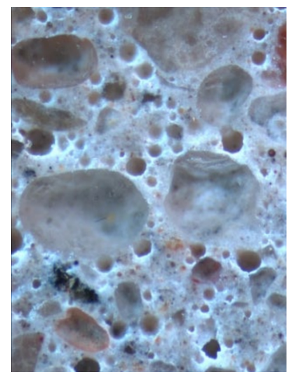
WisDOT Contact

Myungook (MK) Kang
myungook.kang@dot.wi.gov

Background

Concrete pavements in cold climates suffer from freeze-thaw deterioration. Entrained air void systems, miniscule pockets of air created during concrete mixing, mitigate freeze-thaw damage by providing reservoirs for water to expand as it freezes and by suctioning water from surrounding mesopores to reduce pressure within the concrete. Air entraining admixtures (AEA), such as neutralized vinsol resin (NVR) and synthetic alternatives, are added to concrete mixtures to stabilize air bubbles during mixing and ensure a proper entrained air void system develops in the hardened concrete.

Typical air content required for concrete in wet freeze-thaw environments is five to seven percent by volume. Lower volumes can result in reduced performance and lifespan; however, higher volumes can significantly reduce compressive strength. This narrow window of acceptable volume makes accurate measurements of air voids in fresh concrete critical, but current methods often return inconsistent results. The objective of this research was to determine if disparities in air content exist between use of synthetic and neutralized vinsol resin (NVR) air entraining admixtures (AEA).



Air voids measuring 10 µm –1 mm in diameter

Methodology

Fresh concrete from 12 Wisconsin projects was field tested and cored for hardened air void analysis. Concrete samples were taken before and after the slip-form paving, and fresh air contents were measured with pressure (AASHTO T152 and ASTM C231B), gravimetric (AASHTO T121) and volumetric (AASHTO T196) methods. Linear traverse testing (ASTM C457) was conducted on cylinders of these samples and of cores drilled from near the same locations; results were compared to fresh concrete air contents.

Preliminary laboratory tests were performed on two batches of concrete, one made with a sodium olefin sulfonate synthetic AEA and one with an NVR AEA. Two synthetic and one NVR AEAs were selected for further testing on uncompacted and hand-rodded specimens with typical WisDOT properties (4.5 to 7.5 percent air and one to three inches of slump). Each was subjected to atomic force microscopy (AFM), nanoindentation scanning electron microscopy (SEM) and foam drainage testing (FDT).

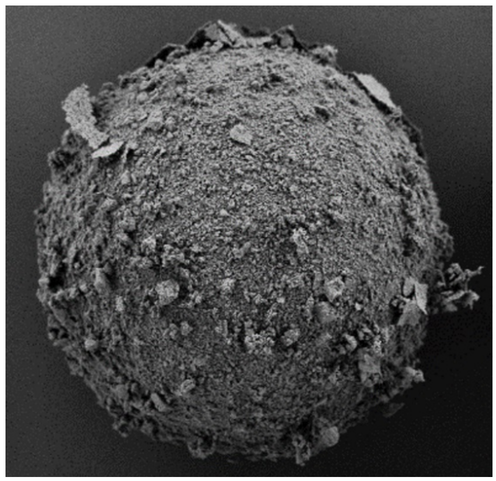
"This study verifies the occurrence of disparities between air content in fresh concrete and hardened concrete, and it identifies the fundamental causes of the disparities. The result of the study will help WisDOT modify field quality control tests to reduce measured air content discrepancies, which will provide more consistent and durable high-quality concrete pavement."
– Myungook (MK) Kang, WisDOT

Interested in finding out more?

Final report is available at: [WisDOT Research website]

Results

Air bubbles entrained with synthetic AEAs were found to be less robust and have lower survivability than those entrained with NVR AEAs. The difference stems from fundamental properties of the bubble shell. On average, bubble shells associated with the two synthetic AEAs were 70 to 75 percent thinner and 37 to 56 percent less stiff than those associated with NVR AEAs. Air loss due to hand-rodding was higher in synthetic AEAs than in the NVR AEA mix, which supports the hypothesis that air bubbles entrained with synthetic AEAs are less stable than those entrained with NVR AEAs under physical impacts such as hand-rodding. In presence of cement, foams derived of synthetic AEAs were significantly less stable than those of NVR.



An SEM image of a bubble shell's outer surface

Results of the AASHTO T152 and ASTM C231 methods were found to be in reasonable agreement (within two percentage points), with differences stemming from sampling procedures. In pavements where synthetic AEAs were used, the ASTM C457 air contents of sampled cylinders were up to five percent lower than those of drilled cores taken at approximately the same location.

Recommendations for implementation

The research team successfully identified the existence and causes of disparities in air content between the use of synthetic and NVR AEAs. The team developed new test protocols to measure the stiffness and thickness of the shells of air bubbles extracted from cement paste and to quantify stability of foams of AEAs in a cementitious environment. These tests can be used in the development of new AEAs and for evaluation of their performance.

When replacing NVR AEAs with synthetic AEAs, manufacturers should adjust their formulas to address higher air loss during hauling, placing and sampling of concrete; larger disparities between quality control tests and actual air contents; and more difficulties in controlling air contents. The Foam Drainage Test was shown to be a practical screening tool for identifying where synthetic AEAs may lead to discrepancies in air content. WisDOT should revisit its incentive structure for air content, as synthetic AEAs introduce a higher level of uncertainty to test results.

This brief summarizes Project 0092-14-05,
"Comparison of Fresh Concrete Air Content Test Methods and Analysis of Hardened Air Content in Wisconsin Pavements"
Wisconsin Highway Research Program