# 2009 BFRL Project Description

**Project Title:** REACT: Reducing Early-Age Cracking Today

September 12, 2008

**Principal Investigator:** Dale P. Bentz, x5865

**BFRL Program:** HYPERCON: Predicting and Optimizing Concrete Performance

**Objective:** To demonstrate reductions in early-age concrete cracking by developing the critical measurement science for quantifying early-age properties and performance and by developing, demonstrating, documenting, and delivering robust mitigation strategies, including shrinkage-reducing admixtures, internal curing, and proportion modifications such as high volume fly ash mixtures.

**Problem:**

***What is the problem?*** While numerous innovations have been successfully introduced to improve concrete and concrete construction in the past 20 years, the prevalence of early-age cracking has actually increased during this time period. In addition to being an aesthetic problem, early-age cracking often totally compromises the (intended) long service life of a concrete structure. A 2003 FHWA nationwide survey identified the following three major distresses for high-performance concrete construction: early-age cracking, corrosion (likely caused by early-age cracking), and cracking of girders[A]. At a 2007 ACI Strategic Development Council (SDC) meeting, early-age cracking issues were estimated to cost the industry $500 M annually, with problems occurring on 50 % of field construction sites. Cracking has thus been identified as an industry critical technology by the ACI-SDC[B]. **The problem is that the critical measurement science infrastructure, in the form of standardized test methods, does not currently exist for assessing two of the main contributors to early-age cracking: thermal and autogenous stresses.**

***Why is it hard to solve?*** Given the large diversity of concrete materials, mixture proportions, and technical background of personnel, only the simplest of field measurement methods has a reasonable chance of being widely adopted by the industry. For this reason, concrete performance is still characterized by extremely straightforward tests for slump, air content (unit weight), and strength. Similarly, for the new mitigation strategies to be widely adopted, detailed specifications on their utilization must be developed and distributed via ACI and the American Society for Testing and Materials (ASTM), which is a slow process due to the consensus nature of these organizations.

---

[A] High Performance Concrete – 2003-2004 Survey Results of State DoT HPC Implementation, FHWA Resource Center, U.S. Department of Transportation, 2004.
[B] http://www.concretesdc.org/projects/technologies.htm, access verified June 2008.

***How is it solved today, and by whom?*** Thermal stresses are regulated by the (semi-adiabatic) temperature rise of the in-place concrete. Academic and industrial researchers are developing simple quantification methods to measure semi-adiabatic temperature rise, but to date, no standards have been drafted within ASTM. Likewise, no standard methods exist for assessing the early-age autogenous deformation of concrete. A test method based on sealed corrugated tubes that was developed in Denmark and is currently being balloted within ASTM for pastes/mortars is not applicable to concrete. Early-age cracking issues are more prevalent in the U.S., perhaps due to the finer cements that are produced in the U.S. relative to the rest of the world. Knowledge on successful mitigation strategies, developed mainly at NIST and Purdue University, has not been consolidated or reduced into practical specifications and guidelines.

***Why NIST?*** By providing the measurement science needed for assessing susceptibility to early-age cracking and the tools and knowledge necessary to implement successful mitigation strategies, this project will provide a predictable and optimized concrete performance, assuring that concrete is able to fulfill its intended function for its designed service life. As one example, NIST (specifically our internal curing web site at http://ciks.cbt.nist.gov/lwagg.html), is currently viewed by the U.S. concrete industry as the go-to source for measurement science information on internal curing, as exemplified by its being referenced on several industry web sites. This project is aligned with the BFRL strategic goal of "Measurement Science for Infrastructural Materials."

**Approach:**

***What is the new technical idea?*** Susceptibility to early-age cracking can be quantified by a set of two simple measurements: semi-adiabatic calorimetry and autogenous deformation. The former is well developed, but not standardized, while further development of the latter measurement is still needed for concrete. The most straightforward approach is to measure autogenous deformation directly on cylinders cast in standard compressive strength molds, using a dial gauge. Temperature control and friction on the cylinder mold walls are critical issues that must be addressed. If these issues can not be overcome, more elaborate measurement techniques, such as sealed ASTM C1581 restrained shrinkage rings or larger corrugated tubes, must be employed. Mitigation strategies that have been demonstrated to reduce autogenous deformation, such as internal curing and shrinkage-reducing admixtures, may also reduce plastic shrinkage (cracking) and increase workability retention. These latter benefits must be quantified via detailed laboratory testing. As these two mitigation strategies do not address thermal stresses, mixture proportion modifications, such as coarser cements, coarse limestone additions, and high volume fly ash mixtures, that address both thermal and autogenous stresses, may be preferred and necessary in practice. Data sets demonstrating the advantages of these modifications must be developed and archived for easy access by the industry.

***Why can we succeed now?*** As witnessed by the interest of the ACI SDC, early-age cracking is now centered on the radar screen of the industry. At the same time, the measurement techniques are maturing to permit their adoption as industry standards. Finally, the industry is now actually willing to evaluate mitigation strategies in demonstration projects to develop viable solutions to what they perceive to be a major and growing early-age cracking problem. The NIST/Purdue University team has the necessary technical skills, the critical industrial contacts, and a proven track record for addressing early-age performance issues.

***What is the research plan?*** The principal investigator will work closely with industrial and academic researchers to achieve the objectives of this project. The standardization of semi-adiabatic calorimetry will be promoted by participation in the activities of the ASTM C01.48/C09.48 joint subcommittee. The viability of autogenous deformation measurements on fresh concrete cylinders will be determined in collaboration with the National Ready-Mixed Concrete Association (NRMCA), who have the facilities to produce concrete and a curing room in which measurements at a constant temperature can be achieved. Efforts to date have demonstrated that while significant deformations can be measured using this technique, a high degree of temperature control is critical to avoid the concrete cylinder behaving as a thermometer (expanding/contracting with internal/external temperature changes). A simple method of controlling specimen temperature using a cooling water jacket will be investigated. To combine thermal and autogenous effects in a single experimental measurement, a semi-adiabatic version of the ASTM C1581 restrained ring shrinkage test will be developed in collaboration with Prof. Jason Weiss of Purdue University.

Past NIST research has successfully demonstrated mitigation strategies for early-age cracking including shrinkage-reducing admixtures, internal curing, and modifications to mixture proportions such as coarser cements or coarse limestone replacements for cement. However, these foundational studies were conducted on paste and mortar specimens. In collaboration with Purdue, these critical demonstrative data sets will be extended to concretes. The advantages of high volume fly ashes mixtures with internal curing with respect to early-age crack resistance will also be quantified through a detailed joint experimental study. The authoritative information produced (past and present) by the research team will be assembled and coordinated into a portal web site that will be the definitive web-based industry-wide resource for the measurement science of early-age properties and performance of concrete, similar to the purpose currently served by the NIST internal curing web site.

**Recent Results:**

**Outputs**: With NRMCA, demonstrated sustainability of blending of crushed returned concrete fine aggregates with lightweight aggregates to provide internal curing and equivalent strength, in a paper/presentation for the 2008 NRMCA Technology Forum: Focus on Sustainable Development

"Reducing Thermal and Autogenous Shrinkage Contributions to Early-Age Cracking," *ACI Materials Journal*, Vol. **105** (4), 414-420, 2008

Invited plenary lecture (Bentz) on "Early-Age Properties of Cement-Based Materials" presented at the 12th International Congress on Chemistry of Cement in 07/07, published in *Cement and Concrete Research* in 02/08, leading to invited article, Bentz, D.P., and Weiss, W.J., "REACT: Reducing Early-Age Cracking Today," *Concrete Plant International*, Vol. **3**, 56-62, June 2008

**Outcome**: Developed a web-accessible nomograph for mixture proportioning for internal curing (http://ciks.cbt.nist.gov/~bentz/ICnomographEnglishunits.pdf, May 2007)

**Outcome**: Bentz was recipient of a 2007 ACI Wason Medal for Materials Research and Expanded Shale, Clay, & Slate Institute Frank G. Erskine awards

**Standards and Codes:**
ACI 231 state-of-the-art report on early-age cracking (Bentz, co-author/editor)

"Standard Practice for Determining Mass Requirements of Lightweight Aggregates to Be Used for Internal Curing Applications" (drafted at the request of the chairperson of ASTM C09.21)

Member of ACI 231 (Early Age) and 308 (Curing) and ASTM C01-Cement and C09-Concrete committees (Bentz)