AUGUST 2016 V. 38 No. 8

Concrete international

The Magazine of the Concrete Community

Mixing, Placing & Curing

American Concrete Institute

Jointless Floors

Fact or Fiction?

The trend toward **JOINTLESS FLOORS** continues to grow anywhere fewer joints, less maintenance and exceptional durability are essential. But are the claims fact or fiction?

You can create control joint/saw cut free floors with larger panel sizes using complex mix designs and installation techniques. But unless you've improved the most essential element – the cement paste, you've only achieved a short-term solution. Komponent® cement technology is engineered to substantially improve the cement paste for the service life of the concrete and maximize floor panel sizes with minimal or no control joints. This high-performance cement technology does not require the use of chemical admixtures and prevents negative side effects like strength loss. It is the only concrete solution proven to maximize performance and minimize maintenance for the service life of the concrete.

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Joint Reduction	90 to 95% Fewer Joints	60 to 80% Fewer Joints
Jointless Slab Size	Up to 150 ft x 150 ft	Up to 60 ft x 60 ft
Floor Flatness/ Floor Levelness	Full Service Life of Concrete	Up to 2 years
Curling	Eliminated	Reduced
Abrasion Resistance	30 to 40% Increase (ACI 223)	Unpublished
Dimensional Stability	Full Service Life of Concrete	Up to 2 Years
Service Life	40 to 80 Years	20 to 40 Years
Expected Shrinkage	Net Zero	> 75% within 2 years
Permeability	3 to 4x Lower	Based on Mix Design
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MIXING, PLACING & CURING

ALSO FEATURING

August

Ci
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A U.S. record high wind tower was recently erected in Adams County, IA, using precast segmental construction. On-site precasting of the tower segments removes limitations on the diameter of the tower base and corresponding height and also allows the use of local labor and locally sourced materials. For more details on this project, see the article starting on p. 29. *(Photo courtesy of Andrea Willer, Senior Project Engineer, Siemens Energy, Inc., Wind Power.)*

departments

IN **Ci**

Consensus is a Continuum

The concrete industry recently held its first workshop toward development of Concrete 2029, a plan for improving the efficiency of the concrete construction industry, the quality of its output, and its public image (for more on this and a future workshop, see "Knowledge to Practice," p. 20). No improvements can be made without measurement, so this initial meeting included assessments of industry strengths, weaknesses, opportunities, and threats (SWOT). As a participant in the workshop, I couldn't avoid making a peripheral SWOT analysis of ACI. My quick assessment indicated that the Institute's greatest strength—consensus—may also be its greatest weakness. Consensus develops somewhere between complacency and controversy, so to ensure that ACI's consensus-based documents maintain the high quality that the concrete industry expects and needs, the status quo must be continually, respectfully challenged through open debate. And that's where *CI* fits in. This month's *CI* includes the following challenges to the status quo:

- Curing water can be more than 20°F (11°C) cooler than the internal concrete temperature (p. 33);
- Formwork serves as more than a mold for fresh concrete (p. 65); and
- Standard industry documents need more explicit guidance regarding concrete setting (p. 53) and for the timing of sawcutting of slipform pavement (p. 41).

Such challenges create opportunities for improvement, helping to protect the Institute and the concrete industry from the threat of complacency.

Rex C. Donahey

President's Memo

Learn Online at ACI University

Michael J. Schneider
ACI President

In my 40+ years in the construction industry, I have come to understand the value and importance of lifelong learning. At the 2015 World of Concrete, I attended the press conference where ACI University was officially launched. ACI University is a training resource that provides online access to a wide range of concrete topics and the opportunity to earn CEU/PDH credits. The content of ACI University has greatly increased since its launch.

You should familiarize yourself with the ACI website, where you will find ACI University. The ACI University app can be downloaded to iOS tablets or smartphones and enables you to view a list of courses, read a course description, and purchase access on mobile devices. With tablets or smartphones that are not iOS devices, you can find a list of courses by accessing the ACI Store through a browser. Courses can be accessed through a browser on any mobile device. All webinars and ACI University courses are available for purchase through the ACI Store. ACI University provides webinars, online/on-demand classes, Certificate Programs, and free online education presentations.

On the first Tuesday of each month, ACI offers a 1-hour webinar, along with longer, in-depth webinars that are scheduled throughout the month. Webinars are offered as an individual registration or a discounted 10-pack registration for groups. I know of companies that take advantage of these webinars each month to allow their professional staff the opportunity to meet their annual professional development requirements. Webinars are recorded so that they can be accessed later. One of the advantages of the live webinar is the opportunity to ask questions of the instructor. The webinars are available going back to March 2015, when the program was launched. Both live and recorded versions provide continuing education credit. For the live webinar, the PDHs are given as part of the log-in process. If you view a recorded session, you must score 80% on a quiz at the end of the webinar to earn the PDHs.

The online/on-demand courses feature a broad range of topics and formats. Some are based on chapters from ACI publications or articles. Others are based on sessions recorded at ACI conventions. Some are highly interactive certification training courses. ACI staff is currently working on a Spanish translation of the three-part Concrete Fundamentals course and additional classes are now being developed.

Some of the 1-hour on-demand courses can be purchased using a member credit. People who have an Individual Membership receive 11 member credits per year. One of the most underused member benefits is the member credits. These credits can be used to download from a large selection of ACI committee documents, Symposium papers, or ACI University online learning courses and earn PDHs (or CEUs) each year. Typically, one credit can be redeemed for a committee document or for a 1-hour online/on-demand course. Unused credits do not accumulate from year to year.

The Certificate Programs consist of all online classes. Certificates can currently be earned in:

- **Anchorage Design**, which covers the basic design principles for anchorage to concrete; the background of ACI 318, Appendix D (currently ACI 318, Chapter 17); example design problems for single-anchor applications; and an understanding of post-installed anchor qualifications;
- **Concrete Fundamentals**, which covers the basic knowledge of the materials used to produce concrete, the importance of proper curing and protection of concrete, batching and mixing, and much more; and
- **Concrete Repair Application Procedures**, which covers basic concrete repair techniques, including the purpose of the repair, applications for which each method is appropriate, surface preparation, safety considerations, and the repair procedure.

The Educational Activities Committee is now evaluating additional certificate programs.

There are also free online education presentations. Members can browse a list of recorded presentations from ACI conventions and other concrete industry events for viewing online. Currently, the ACI website has more than 376 presentations available. Each week, a new presentation is featured, complete with a soundtrack and the presenter's slides. These then are added to the archives. If you missed the last ACI convention, you can still watch many of the presentations.

Are you maximizing your individual or organization's benefits from your ACI membership? Have you used any of your 11 member credits this year? Have you participated in any of the ACI webinars? If the answer to any of these questions is "no," I encourage you to take advantage of the products provided by ACI University. If you have not already downloaded the ACI University app, you should do so today.

Michael J. Schneider
American Concrete Institute

ACI Sustaining Members

are the foundation of our success.

To provide additional exposure to ACI Sustaining Members, *Concrete International* includes a 1/3-page member profile and a listing of all Sustaining Member organizations. All Sustaining Members receive the 1/3-page profile section on a rotating basis.

ACS Manufacturing Corporation
Advanced Construction Technology Services
American Society of Concrete Contractors
Ash Grove Cement Company
Ashford Formula
Baker Concrete Construction, Inc.
Barrier-1 Inc.
BASF Corporation
Bauman Landscape & Construction
BCS
Braun Intertec Corporation
Buzzi Unicem USA
Cantera Concrete Company
CHRYSO, Inc.
Concrete Reinforcing Steel Institute
Construction Forms, Inc.
CTLGroup
Dayton Superior
Ductilcrete Slab Systems, LLC
The Euclid Chemical Co.
Fibercon International, Inc.
Future Tech Consultants
W.R. Grace & Co.
Headwaters Resources, Inc.
Holcim (US) Inc.
Keystone Structural Concrete, LLC
Kleinfelder
Kryton International Inc.
Lafarge North America
Lithko Contracting, Inc.
Mapei
Mason Construction, Ltd.
Meadow Burke
W. R. Meadows, Inc.
Metromont Corporation
MTL
Multiquip Inc.
Municipal Testing
North S.Tarr Concrete Consulting PC
Oztec Industries, Inc.
Pacific Structures
Penetron International Ltd.
Portland Cement Association
Precast/Prestressed Concrete Institute
Riggs Contracting
S. K. Ghosh Associates, Inc.
Saudi Building Code National Committee
Seretta Construction Inc.
Sika Corp.
Specialty Products Group, Inc.
STRUCTURAL
Structural Services, Inc.
Tekna Chem
TWC Concrete Services
Wacker Neuson

BASF is a global leader of chemical solutions for new construction, maintenance, repair, and restoration of structures. Through their Master Builders Solutions brand, they offer products, solutions, and expertise that improve durability, water resistance, energy efficiency, safety, and aesthetics. The North American Construction Chemicals division of BASF is comprised of four business lines:

The Admixture Systems business is a leading innovator of advanced products that are used to improve the placing, pumping, finishing, appearance, and performance characteristics of concrete supplied to the ready mixed, precast/prestressed, concrete masonry, paving, and underground construction markets.

The Construction Systems business supplies premier products that provide joint sealant, waterproofing, grout, concrete repair, water repellent, performance flooring, surface adhesives, and wall-coating solutions for new construction and renovations projects.

BASF's Wall Systems business provides a full line of exterior wall systems including exterior insulation and finish systems (EIFS), stucco, and textured acrylic surfacing systems.

Through the Watson Bowman Acme business, BASF develops and manufactures expansion control systems for the construction industry.

At BASF, they create chemistry for sustainable construction around the globe.

For more information about Master Builders Solutions brand products, visit **www.master-builders-solutions.basf.us** or call +1.800.628.9990.

To learn more about our sustaining members, visit our website at www.concrete.org/sustainingmembers

Their dedication to ACI is appreciated. Their willingness to share knowledge and their continued support have greatly enhanced the progress of the concrete industry.

CRSI Concrete Reinforcing Steel Institute

Founded in 1924, the Concrete Reinforcing Steel Institute (CRSI) is a technical institute and Standards Developing Organization (SDO) that stands as the authoritative resource for steel-reinforced concrete construction.

Serving the needs of engineers, architects, and construction professionals, the Institute publishes a variety of industry-trusted technical publications including standards documents, design aids, and reference materials, and offers on-demand and local educational opportunities. The CRSI website contains free technical information and online tools to aid in project development and design.

CRSI Industry members include manufacturers, fabricators, material suppliers, and placers of steel reinforcing bars and related products. Their Professional members are involved in the research, design, and construction of steel-reinforced concrete structures and pavements. CRSI's nationwide Region Professional network assists both members and industry professionals and creates awareness among the design/construction community.

The non-profit CRSI Research & Education Foundation fosters the mission of the Institute through educational programs and research scholarships for students majoring in civil engineering, architecture, and other related disciplines at universities and technical schools.

CRSI is headquartered in Schaumburg, IL, with offices across the United States. For more information, visit **www.crsi.org** or contact them at +1.847.517.1200 or **info@crsi.org**.

KLEINFELDER Bright People. Right Solutions.

Kleinfelder is an employee-owned company consisting of architects, engineers, inspectors, and scientists that provides solutions to meet our world's complex infrastructure challenges.

Their recent projects include providing design for the Alewife Parking Garage for the Massachusetts Bay Transportation Authority which included evaluating structural deficiencies, correcting deterioration problems, developing repair details and providing construction staging plans to limit impacts to the public. In Salt Lake City, UT, Kleinfelder completed special inspection and materials testing services for the four-story, 172,000 sq. ft. ultramodern Public Safety Building. The foundation consisted of 10,000 cubic yards of concrete, and required multiple inspectors and an on-site laboratory to ensure the quality for the owner.

In the Pacific Northwest, Kleinfelder provided quality assurance, special inspection, and materials testing for the Snoqualmie Falls Hydropower Redevelopment project. Creative placement and testing techniques were employed to deliver the concrete, and approximately 40,000 cubic yards of concrete were placed to construct the new structures using high percentages of fly ash and nitrogen-cooled concrete for temperature control.

For more information about Kleinfelder, visit their website at **www.kleinfelder.com** or call +1.858. 320.2000.

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GRACE CONSTRUCTION & PACKAGING

Grace Construction Products (www.graceconstruction.com) is a global leader in developing and marketing products for the construction industry.

Grace is a provider of technically superior concrete admixtures, fibers, surface treatments, and liquid pigments that make concrete stronger, longer-lasting, crack-resistant, aesthetically pleasing, and cost-efficient. The company also manufactures cement-processing additives; concrete masonry products; air and vapor barriers; roofing underlayments; self-adhered window, door, and deck flashings; structural waterproofing systems; and fire protection products.

Grace is known for innovation in product development and technology as well as world-class technical services, facilities, and staff. Grace's quality construction materials can be found in nearly every major project around the globe, from the White House to the Pentagon, the Library of Congress to the Smithsonian, the London Underground to the Bank of China in Hong Kong, and the infrastructures of the Middle East and Eastern Europe.

To learn more about Grace Construction Products, please visit their website at **www.graceconstruction.com**.

Letters

Reflections on an Evangelistic Concrete Technologist

The "In Remembrance" description of Ken Day's long career (*Concrete International*, May 2016, p. 11) included many of his accomplishments, but said little about the man himself, who was 85 years old when he died. In mid-March, his son John sent a summary of Ken's life to me, via James Aldred. It began with a simple statement: Ken Day, FACI, passed quietly on March 17, 2016.

Those who have known him might agree that this was one of the few times Ken ever did anything quietly. He described himself as "an evangelistic concrete technologist" and said that meant concrete technology was his religion and he wandered around the world preaching it to anyone who would listen (and many who didn't).

According to John, Ken was actually more specialized than that. His expertise was mainly in the areas of mixture design, quality control, and specification—although he had stints as a consulting structural engineer, a university lecturer, a precast and prestressed concrete producer, and a general investigator and an expert witness on cases involving defective concrete.

> *"Don't confuse quality control at the concrete plant with check testing at the jobsite."*

I came to know Ken about 10 years ago when I wrote a review of the third edition of his book, *Concrete Mix Design, Quality Control and Specification*. Reading the book was an adventure for me because I learned about a completely different approach to concrete quality control than the one I had been taught in college. An amplification of his quality control mantra could perhaps be paraphrased as follows: Don't confuse quality control at the concrete plant with check testing at the jobsite. The latter gives us results that are generally too late to be of any use. That view was summarized as follows in the third edition: "It is far more economical to ensure that no significantly defective concrete is produced at a plant than to ensure that no defective concrete is accepted at particular delivery points…"

More than once, Ken wrote articles and letters to the editor chastising engineers who, he believed, were approaching quality control in entirely the wrong way. Many specifiers of concrete will certainly remember Ken for his strongly worded and very public attacks on traditional specifications. He was particularly critical of prescriptive specifications, arguing that they were essentially preventing concrete producers from improving their practices.

He was an early admirer of NRMCA's P2P movement that advocated changing from prescriptive to performance specification. He believed that approach would result in owners receiving satisfactory concrete at a minimum cost. Note his careful choice of the word "satisfactory" rather than "high quality." Satisfactory concrete was, in Ken's view, economical concrete fit for service. Nothing more, nothing less.

In recent years Ken had come to be regarded as less of a rebel than in his early days. But I prefer to remember him as a contentious person who could back his sometimes unpopular opinions with reams of data rather than a single anecdotal retort.

Thanks to son John, who is following his father's path in the concrete industry, and provided most of the information included in the obituary and this letter.

Ward R. Malisch, ACI Honorary Member, Lebanon, TN

News

ASCC 15th Annual Conference in Minneapolis

The American Society of Concrete Contractors (ASCC), St. Louis, MO, will hold its 15th Annual Conference, September 15-18, 2016, at the Doubletree, Bloomington-Minneapolis South, Minneapolis, MN.

Industry experts, including Rocky Geans, L.L. Geans Construction Co.; Linda Figg, FIGG Bridge Group; Jeff Coleman, The Coleman Law Firm; and Kevin MacDonald, Beton Consulting Engineers, will offer seminars on critical industry topics. CEMEX leaders and contractors will present an 8-hour Legacy Safety Leadership Program designed for concrete executives and safety directors. The workshop provides the tools, skills, and behaviors to lead safer, more efficient operations and to achieve the goal of zero incidents. This workshop is limited to 40 attendees.

Additional half-day workshops, designed to foster interaction between presenters and participants, will cover “Creating the Canvas for a Polished Floor” and “Parking Lot Boot Camp.” Geans will present his 2-day Business School. “Creating the Canvas for a Polished Floor” will also include the use of outdoor demo slabs to illustrate a variety of slab conditions. Seminar topics include “The Wood First Initiative,” “Contracts—Ask the Lawyer,” “Responsibility in Concrete Construction,” “New Ways to Measure Floor Tolerances,” and a panel discussion with decorative concrete contractors.

The ACI Flatwork Finisher Certification class and exam will be offered September 15. For more information, visit **www.ascconline.org** or call +1.866.788.2722.

ASTM Sustainability Committee Developing Resiliency Guide, Definitions, Symposium

ASTM International’s Committee E60, Sustainability, is drafting a guide to help standards developers consistently evaluate the resiliency of products and materials. The guide will include a consensus-driven definition of resiliency and is designed to apply to all applications and market segments, according to ASTM member Michael Schmeida.

“The topic of resiliency is becoming more discussed both in ASTM and outside by a variety of parties,” states Schmeida, Director of Technical Services at The Gypsum Association. “But there is not a definition of resiliency developed in a consensus manner, nor one that covers the concept at high level.”

The proposed standard (WK54254) will help people determine what materials and products are best suited, in terms of resiliency, for various applications. According to Schmeida, the primary users of the guide will be other standards developers looking to better define resiliency for their product types. Designers and consumers could also use the guide to make more environmentally conscious and sustainable purchases.

As Chair of E60, Schmeida notes that the committee is planning an October 2017 symposium on the paradigm among safety, resiliency, and sustainability. Those interested in participating are encouraged to e-mail the Symposium Chair and E60 Vice Chair Emily Lorenz at emilyblorenz@gmail.com.

Committee E60 welcomes participation in all of its activities. Become a member at **www.astm.org/JOIN**.

TMS Cast Stone Committee Standards Open for Public Comment

The Cast Stone Committee of The Masonry Society (TMS) has completed balloting of three new proposed standards:

- Standard for the Design of Architectural Cast Stone (TMS 404);
- Standard for the Fabrication of Architectural Cast Stone (TMS 504); and
- Standard Specification for the Installation of Architectural Cast Stone (TMS 604).

In accordance with TMS rules, standardized documents must be open for public comment for a period of not less than 45 days. A Working Draft of the proposed standards can be accessed at **www.masonrysociety.org/html/committees/tech/csc/Cast_Stone_Standards_Public_Comment_Announcement_2016.htm**.

Comments from the public on the proposed standards will be accepted through 11:59 p.m. EST on August 20, 2016. Contact info@masonrysociety.org for more information.

Student Teams Receive EPA Grants for Innovative Sustainable Projects

The U.S. Environmental Protection Agency (EPA) announced 38 People, Prosperity, and the Planet (P3) grants to university student teams for proposed projects to develop new, sustainable products and strategies. Each team will receive up to $15,000 for their proposals. Since 2004, the competition has funded more than 600 student team projects nationwide—some leading to start-up companies.

"This year's P3 teams have created innovative research projects that tackle some of our most pressing environmental and public health challenges," said Thomas A. Burke, EPA's Science Advisor and Deputy Assistant Administrator of EPA's Office of Research and Development. "These students have the opportunity to bring their exciting new ideas for innovation in sustainability to life, by expanding their learning experience beyond the classroom."

Funding for the P3 competition is divided into two phases. Teams selected for Phase I awards receive grants of up to $15,000 to fund the development of their projects, which are then showcased at the National Sustainable Design Expo in the spring. Following the Expo, P3 teams compete for Phase II awards of up to $75,000 to further develop their designs and potentially bring them to the marketplace.

This year's teams are testing innovative ideas such as repurposing chemical by-products from the mining industry into new concrete that helps inhibit the corrosion of steel and developing a food waste collection kiosk that will spur food waste to energy production in the local community.

Previous P3 teams have used their sustainable ideas and gone on to start businesses. Lucid Design traces its beginnings back to EPA's first P3 award to the founders' Oberlin College team in 2004. Lucid Design specializes in tracking and analyzing energy consumption and resource use data for clients that include Google and Sony. In 2011, a P3 team from Embry-Riddle Aeronautical University developed a portable, solar-powered, water purification system in the form of a backpack. The team went on to launch AquaSolve Ventures to produce backpacks that are capable of purifying an impressive 4300 gal. (16,000 L) of water a day.

View the P3 winners at **www.epa.gov/P3/20152016-p3-grant-recipients**.

CSI Forum 2016 on Climate Action

The World Business Council for Sustainable Development's (WBCSD) Cement Sustainability Initiative (CSI) announced its 10th annual forum meeting will take place December 13-14, 2016, in Madrid, Spain. The meeting will be co-hosted by CEMEX and CRH.

Discussions this year will focus on climate and energy. Since the Paris Agreement set the wheels in motion last December, government, business, and society are addressing the realities of climate change in coordinated and practical ways. Together with its members, the CSI has demonstrated the leading vision of the cement sector in emissions monitoring and management—but this is just the beginning.

Individually and collectively, companies globally continue momentum on climate actions by tackling the challenge from multiple angles: fuels, emissions, manufacturing technologies, new products, water management, and landscape stewardship, to name a few. But with a challenge so large and multifaceted, cement companies are eager to learn from experts with fresh ideas and insights. 2016 will also mark the 10th round of data collection of the CSI's Getting-the-Numbers Right (GNR) database.

For more information, visit **www.wbcsdcement.org/forum-2016**.

AGC Picks Student Groups for Outstanding Chapter Awards

Iowa State University (ISU), Oregon State University (OSU), and California State University (CSU), Chico, are home to the top U.S. collegiate construction associations this year, according to an analysis of award applications conducted by the Associated General Contractors of America (AGC). The groups each received the association's Outstanding Student Chapter award. "These student chapters have demonstrated exceptional skill and experience that will serve them—and our industry—well in the future," said Chuck Greco, AGC President and Chair of Houston, TX-based Linbeck Group.

The ISU AGC student chapter was selected for its work repairing homes in the Ames, IA, community as well as communities in need in Tennessee and Nevada. With 67 student chapter members involved, they assisted more than 10 families in need over the year. The student chapter received $1500 from the national association to help finance their operations.

The OSU AGC student chapter was selected based on its workforce development programs and service. The student chapter created the first high school AGC student chapter at

ACE Academy in Portland, OR. They also reached out to middle school students to teach them about the construction industry through building games and other programming.

The CSU, Chico, AGC student chapter was recognized for its work in multiple community service projects. Chico participated in Career GPS, a 1-day event exposing 6000 regional high school students to CSU, Chico's Construction Management Department and the AGC. AGC student members completed a Blitz Plant project where students participated in the pre-planning and planting phases of 32 native trees around the City of Chico in areas of need. Students also participated in an ACE Mentor program, where AGC student chapter members helped promote the construction industry among high school students through a project/competition over the course of a year.

A panel of five judges representing a cross section of the construction industry evaluated the applications for this year's Student Chapter Awards contest. School groups were rated based on their accomplishments during the 2014-2015 academic year. There are approximately 180 university-level student AGC construction groups nationwide.

In Remembrance

John W. Roberts, FACI, passed away on June 14, 2016. He was 97 years old. He was the Chairman of Northeast Solite Corporation, Richmond, VA. Roberts served on ACI Committees 130, Sustainability of Concrete; 224, Cracking; 308, Curing Concrete; 325, Concrete Pavements; and formerly 362, Parking Structures. He was a Past President of the Virginia Section, American Society of Civil Engineers (ASCE). His awards include the ACI Sustainability Award, ACI Cedric Willson Lightweight Aggregate Concrete Award, ACI Wason Medal for Materials Research, the Swarthmore College McCabe Engineering Award, and the Heaton Award presented at the Leadership Conference in Blue Ridge, NC. He was also recognized as the Outstanding Industrialist of the Year by the Virginia Science Institute. Roberts received his BS from Swarthmore College, Swarthmore, PA, in 1939.

New Attendance Record for The ACI Concrete Convention and Exposition – Spring

An all-time attendance record for an ACI spring convention has been set. With 1831 attendees in Milwaukee, WI, at The ACI Concrete Convention and Exposition – Spring 2016, it was the highest attended spring convention to date—and the second-highest convention total overall.

The principals from the Wisconsin Chapter – ACI Convention Committee who helped organize the event comprised Jeff Anderson, GeoTest, Inc., and Laura Powers, WJE, Co-Chairs; Adam Tamme, ATC, Treasurer; Ryan Olson, AC Business Media, Publicity; Greg Schmidt, GeoTest, Inc., Guest Program; and Josh Skogman, Mortenson Construction, Contractors' Day. Anderson oversaw the Technical Program, Powers chaired the Student Program, and Ramme guided the Social Events. Alain Belanger was the ACI Convention Committee Liaison.

Convention Exhibitors

Airmatic Inc.; American Engineering Testing, Inc.; Aquafin, Inc.; BarSplice Products; BASF Corporation; Burgess Pigment Company; Buzzi Unicem USA; Cervenka Consulting; CMEC; COMMAND Center – A division of the Transtec Group; Composite Rebar Technologies; Con-Cure, LLC; Concrete Cares; Concrete Sealants, Inc.; Corro-Shield International, Inc.; Decon USA Inc.; ELE International; The Euclid Chemical Company; FlackTek, Inc.; Forney LP; FORTA Corporation; Germann Instruments, Inc.; Giatec Scientific, Inc.; GCP Applied Technologies; Headed Reinforcement Corp.; James Instruments, Inc.; Kryton International Inc.; Laser FF, LLC; MBW Inc.; MTS Systems Corporation; Premier CPG; Primekss; Portland Cement Association; Proceq USA, Inc.; QuakeWrap, Inc.; Radarview/UCT; Sika Corporation; Silica Fume Association; Skyway Cement Company; STRUCTURAL TECHNOLOGIES; The Fischer Group – Cure Right Curing Covers; Trinity Lightweight; Vector Corrosion Technologies; Wacker Neuson; and Zircon Corporation.

Notable events at the ACI Convention – Spring 2016, held April 17-21, 2016, included:

Awards Bestowed

The convention's Opening Session featured the presentation of ACI awards, which included five Honorary Memberships, 30 Fellows, and the Instituto del Cemento y del Hormigón de Chile, the Wisconsin Ready Mixed Concrete Association, and 42 individuals receiving personal and paper awards.

The Excellent and Outstanding ACI Chapters for 2015 were announced. The winning chapters are:

- **Excellent Chapters**—Arkansas, Carolinas, Ecuador, Georgia, Greater Miami Valley, Guatemala, India, Indiana, Kansas, Louisiana, Maryland, Missouri, Nebraska, New Jersey, New Mexico, Northeast Mexico, Peru, Pittsburgh Area, San Diego International, Southern California, and Wisconsin; and
- **Outstanding Chapters**—Concrete Industry Board New York City, Eastern Pennsylvania and Delaware, Florida First Coast, Las Vegas, Northern California and Western Nevada, Quebec and Eastern Ontario, Rocky Mountain, Singapore, Virginia, and Washington.

2015 ACI Excellent and Outstanding University Awards

Through their participation in ACI activities, 39 colleges and universities achieved 2015 ACI Excellent and Outstanding University Awards. The criteria for earning points toward these awards can be found at **www.concrete.org/students/universityaward.aspx**.

The schools that qualified for ACI Excellent University Awards are Arizona State University, Auburn University, Missouri S&T, National Polytechnic Institute, New Jersey Institute of Technology, North Carolina State University, Pennsylvania State University, Polytechnic University of Puerto Rico, San Jose State University, Texas State University, Universidad Autónoma de Nuevo León, Universidad Rafael Landívar Campus Quetzaltenango, Universidad San Francisco de Quito, Université de Sherbrooke, University of Alabama, University of Arkansas – Fayetteville, University of Illinois at Urbana-Champaign, University of Manitoba, University of Minnesota – Duluth, University of North Carolina at Charlotte, University of Puerto Rico – Mayagüez, and University of Texas at Austin.

The 2015 ACI Outstanding University Awards went to British Columbia Institute of Technology, Cleveland State University, Instituto Tecnóligico de La Paz, NED University of Engineering and Technology, Michigan Technological University, Middle Tennessee State University, Pittsburg State University, Rose-Hulman Institute of Technology, Universidad Galileo, University of Colorado Denver, University of Engineering and Technology Lahore, University of Florida, University of Georgia, University of Kansas, University of Victoria, University of Windsor, and University of Wisconsin–Madison.

Fly Ash in Concrete Tribute to Tarun Naik

Tarun R. Naik, FACI, Professor and Founding Director of the University of Wisconsin–Milwaukee (UWM) Center for Byproduct Utilization, was recognized during a technical session in his honor for his significant contributions to the beneficial application of fly ash in concrete. Session moderators included Konstantin Sobolev, UWM, and Bruce W. Ramme, We Energies.

Convention Sponsors Acknowledged

Support for The ACI Concrete Convention and Exposition – Spring 2016 was provided by:

- **Cement Sponsor:** Baker Concrete Construction;
- **Admixture Sponsors:** BASF, The Euclid Chemical Company, GCP Applied Technologies, and Wacker Neuson;
- **Fine Aggregate Sponsors:** AMSYSCO, Carolinas Chapter – ACI, Iowa Chapter – ACI, Northern California and Western Nevada Chapter – ACI, and Trinity Lightweight;
- **Water Sponsors:** Alberta Chapter – ACI, Arizona Chapter – ACI, Arkansas Chapter – ACI, Colorado Ready Mixed Concrete Association, Concrete Industry Board New York City Chapter – ACI, CRC Press – Taylor & Francis, Eastern Pennsylvania and Delaware Chapter – ACI, Georgia Chapter – ACI, Greater Michigan Chapter – ACI, Houston Chapter – ACI, Illinois Chapter – ACI, Intermountain Chapter – ACI, Kansas Chapter – ACI, Las Vegas Chapter – ACI, Louisiana Chapter – ACI, Maryland Chapter – ACI, National Capital Chapter – ACI, New Mexico Chapter – ACI, Northeast Texas Chapter – ACI, Pittsburgh Area Chapter – ACI, Portland Cement Association, Rocky Mountain Chapter – ACI, San Diego Chapter – ACI, Southern California Chapter – ACI, and Wisconsin Ready Mixed Concrete Association; and
- **Registration Bags:** American Transmission Company; CG Schmidt; Computerized Structural Design; FESCO Direct; GeoTest, Inc.; Gestra Engineering; Hammel, Green, and Abrahamson; International Concrete Products; Mortenson Construction; and We Energies.

Upcoming ACI Convention in Philadelphia, PA

Engineers, architects, contractors, educators, manufacturers, and material representatives from around the world will convene at the Philadelphia Marriott Downtown Hotel in Philadelphia, PA, October 23-27, 2016, to collaborate on concrete codes, specifications, and standards. Technical and educational sessions will provide attendees with the latest research, case studies, best practices, and the opportunity to earn professional development hours (PDHs).

The convention host is the Eastern Pennsylvania and Delaware Chapter – ACI, and they plan to showcase the companies, projects, current events, and landmarks that inspired the convention theme of "Revolutionary Concrete." Convention highlights that attendees can look forward to include:

- International Lunch with special guest Andreas Tselebidis;
- Student Mortar Workability Competition;
- Student Lunch with speaker Kenneth C. Hover;
- Contractors' Day Lunch with speakers Mike Ricchezza and Valerie Giangiulio-Moody;
- Concrete Mixer held at the National Constitution Center; and
- Concrete Sustainability Forum 9.

Online registration is open and discounted rates are offered until September 25, 2016. To learn more about the ACI Convention and to register, please visit **www.aciconvention.org**.

PCA Centennial Celebration Continues

Concluding event takes place at the PCA Fall Congress in Chicago, IL

The Portland Cement Association (PCA) is recognized as a leading authority on the technology, economics, and applications of cement and concrete. Through a series of "Centennial Celebration" events throughout 2016, PCA is commemorating its centennial. The first event was the Centennial Celebration Reception and Banquet held on March 14, during the PCA Spring Congress at the Renaissance Blackstone Chicago Hotel, and the last celebration event will be on August 30, during the PCA Fall Congress at the InterContinental Chicago Magnificent Mile, both in Chicago, IL.

Other celebrations have included a reception in Washington, DC, on May 24, during the DC Fly-In and a joint PCA/CTLGroup outing at the PCA Campus in Skokie, IL, on July 27.

"Nearly 100 years ago, PCA's first chairman remarked that unlike many other human activities, building with cement and concrete adds to the permanent wealth of a community," said James G. Toscas, President and CEO of PCA. "Today, as we look upon the extensive transportation systems and magnificent cities that we have built since then, and that will continue to serve us today and in the future, we see the truth of those words."

While building with concrete offers measurable benefits, some of its advantages go beyond numbers. "For example, people feel safer in concrete buildings," Toscas remarked. "Resilient concrete homes resist fire and can withstand storms. They are also solid, quiet, and low-maintenance. People have a sense that the concrete roads and bridges that connect our communities are durable, efficient, and long-lasting."

"As long as there is civilization, there will be a need for concrete," he concluded.

The following is a list of highlights in the history of PCA. The timeline of some significant events in the concrete construction industry during PCA's 100 years of operation is reprinted courtesy of PCA from *Design and Control of Concrete Mixtures*.

For more information, visit **www.cement.org**.

PCA Milestones

- **1916:** PCA is founded and begins operations with 53 cement company members, a headquarters office in Chicago, eight district offices, and a total of 121 employees;
- **1918:** Duff Abrams, PCA's first Head of Research, published his landmark bulletin on concrete mixture design that established the relationship between water-cement ratio and concrete strength;
- **1926:** PCA moved to new headquarters and laboratory facilities near downtown Chicago. In the new lab, research shifted from producing cement and concrete with uniform qualities to addressing basic durability and performance of roads, buildings, and bridges;
- **1938:** PCA's Head of Research, T.C. Powers, documented air entrainment as a method of making concrete frost-resistant and less susceptible to damage from freezing-and-thawing cycles;
- **1948:** PCA built the largest and best-equipped laboratory in the world devoted exclusively to cement and concrete. The building, which now houses CTLGroup, contained more than 2 acres (0.8 ha) of floor space and cost $3 million, including land and equipment;
- **1958:** PCA added a structural laboratory and a fire research center to its research facilities;
- **1962:** Construction of Marina City in Chicago broke the 500 ft (152 m) high barrier for reinforced concrete buildings and fueled concrete's entry into high-rise buildings, previously the domain of steel. PCA consulted on the project's design and construction procedures;
- **1968:** PCA moved its headquarters to a newly completed general office building in Skokie, IL, consolidating operations at what was known at the time as the Cement and Concrete Center, which was also home to the laboratory facilities;
- **1987:** PCA's research and development laboratories became a wholly-owned, for-profit subsidiary of PCA called Construction Technology Laboratories, Inc., now operating as CTLGroup; and
- **1989:** Higher concrete strengths and innovations such as pumping lead to a succession of record-breaking high-rises in Chicago: Two Prudential Plaza reached 915 ft (279 m), and 311 South Wacker topped out at 959 ft (292 m).

1900

1902 The Association of American Portland Cement Manufacturers is founded

1904 The American Society of Testing and Materials publishes ASTM C-1 *Standard Specification for Natural and Portland Cement*

1904 Portland cement from throughout the U.S. is featured at the World's Fair in St. Louis as the magic powder that will revolutionize the century

1905 National Association of Cement Users (NACU) holds its first convention in Indianapolis

1908 Thomas Edison invents cast-in-place concrete housing system

1910

1913 NACU changes its name to the American Concrete Institute

1916 Portland Cement Association is founded in Chicago; previously called the Association of American Portland Cement Manufacturers

1916 PCA publishes *Proportioning Concrete Mixtures and Mixing and Placing Concrete*

1918 Abrams (Lewis Institute—now IIT) publishes the relationship between water to cement ratio and strength of concrete (LS001)

1920

1921 PCA starts long term field and lab study on concrete's resistance to sulfate soils

1925 Abrams publishes *Studies of Bond Between Concrete and Steel* (LS017)

1925 PCA Research lab moved to 33 West Grand Avenue

1926 PCA Fellowship at National Bureau of Standards

1930

1930 National Ready Mixed Concrete Association is founded

1931-1936 Hoover Dam construction

1938 Powers (PCA) discovers that air entrainment gives frost resistance to concrete

1940

1941 A long-term field study of cement performance on concrete using 27 cements of various properties is established (RX026)

1946 The Influence of gypsum on the hydration and properties of portland cement paste (RX012)

1947 Pressure and volumetric methods to determine air content of fresh concrete (RX019)

1948 PCA Research and Development Laboratories builds a central research laboratory in Skokie, Illinois

1948 Studies of the physical properties of hardened portland cement paste (RX022)

1949 Air requirements of frost resistant concrete (RX033)

1950

1951 New York test road demonstrates the importance of air entrainment (RX038)
1951 Linear traverse technique for measuring air in hardened concrete (RX035)
1952 Effect of air on durability of concrete made with various sizes of aggregate (RX040)
1955 Concrete stress distribution in ultimate strength design (DX006)
1955 Permeability of portland cement paste (RX053)
1955 Observations of alkali aggregate reactivity (RX054)
1956 ACI Committee 318 accepts ultimate strength design as an alternate to straight line theory
1956 Pore structure of hardened concrete (RX073)
1956 Effect of various deicers on salt scaling of concrete (RX083)
1957 Plastic shrinkage and shrinkage cracking (RX081)
1957 Curing requirements for scale resistant concrete (RX082)
1957 The PCA Structural Laboratory is built with high strength steel using cast-in-place, precast, and tilt-up concrete and includes a test floor capable of resisting over 4.5 million kg (10 million pounds) to handle full sized elements
1958 The PCA Fire Research Laboratory is built to study the fire resistant properties of concrete
1958 Carbonation of hydrated portland cement (RX087)
1958 Physical structure and engineering properties of concrete (RX090)
1958 Setting of portland cement (RX098)
1959 Criteria for ultimate strength design is developed (DX031)

1960

1960 Concrete mix water purity (RX119)
1960 Chemistry of hydration of portland cement (RX153)
1962 Tobermorite gel—the heart of concrete (RX138)
1963 Optimum steam curing of precast concrete (DX062)
1965 Brewer establishes moisture migration of concrete slabs on ground (DX089)
1965 Fatigue of reinforcing bars is evaluated (DX093)
1966 Seismic properties of reinforced concrete (DX107)
1967 Properties of portland blast-furnace slag cement (RX218)
1968 Shear and moment transfer between concrete slabs and columns (DX129)

1970

1971 to 1973 Fire tests on concrete floors and beams is conducted (RD004 to RD009, RD016)
1977 Stress-strain relationship of high strength concrete (RD051)
1979 Effects of high-range water reducers on concrete (RD061)

1980 1990 2000 2010

1981 Whiting developed rapid chloride permeability test (RD81/191)
1983 Effect of fly ash on air void stability (RD085)
1985 Effect of fly ash on the properties of concrete (RD089 and RD090)
1986 Effect of vibration on the air void system and durability of concrete (RD092)
1988 Flexural and shear behavior of concrete beams during fire (RD091)
1989 Influence of design and materials on the corrosion resistance of steel in concrete (RD098)

1992 Long term performance of field concrete (RD102)
1992 Fire resistance and fire rating for concrete columns (RD101)
1992 Optimization of sulfate form and content (RD105)
1992 Effects of conventional and high range water reducers on concrete properties (RD107)
1994 Engineering properties of commercially available high strength concrete (RD104)
1995 Optimizing surface texture of concrete pavements (RD111)
1996 The influence of casting and curing temperatures on fresh and hardened concrete (RD113)
1996 Use of limestone in portland cement (RP118)

2000 National Concrete Placement Technology Center is founded
2001 Long term performance of concrete in seawater is evaluated (RD119)
2001 Frost and deicer scaling resistance of high strength concrete (RD122)
2002 40 year performance of concrete in outdoor test facility (RD124)
2002 Performance of concrete in sulfate environments (RD129)
2004 Frost durability of roller compacted concrete pavements (RD135)
2004 Translucent concrete patented
2005 Long term performance of architectural panels (RD133)
2005 Chemical path of ettringite formation in heat cured mortar and its relationship to expansion (DEF) (SN2526)
2006 Effect of minor elements on cement performance (RD130)
2007 Hydraulic design of pervious concrete (EB303)
2007 Life cycle inventory of portland cement concrete (SN3011)
2007 Diagnosis and control of alkali-aggregate reactions in concrete (IS413)
2008 Factors affecting formation of air-void clustering (SN2789a)
2009 Blast resistant design for concrete structures (EB090)
2009 MIT Concrete Sustainability Hub is founded

2010 The world's tallest building, Burj Khalifa, Dubai UAE is completed
2010 Life cycle assessment of pavements (SN3119a)
2011 Use of limestone in cements at levels up to 15% (SN3148)
2012 Life cycle evaluation of concrete buildings (SN3119)
2013 Rapid test to determine alkali-silica reactivity of aggregates using autoclaved concrete prisms (SN3235)
2014 ACI 318-14 reorganized
2014 Product category rules developed for cement
2016 Environmental product declaration developed for cement (industry average)
2016 PCA Centennial

Knowledge to Practice: ACI Foundation

Research Project to Help Unify Durability Specifications

Earlier this year, the ACI Foundation's Concrete Research Council (CRC) approved the funding of four deserving research projects. This edition of *Knowledge to Practice* features one of the four projects; the subsequent three editions will focus on each of the remaining research concepts.

Establishing unified durability guidance on chloride ion limits, freezing-and-thawing performance, and external sulfate attack for ACI documents

A recent review of ACI documents pertaining to information on chlorides in concrete revealed that considerable disagreement exists between five different ACI guidance documents. ACI 201, 222, 301, 318, and 350 are not in accord concerning chloride limits in new concrete, strength, and air content for avoiding freezing-and-thawing-related damage and strength requirements for avoiding sulfate damage. These discrepancies between documents have led to confusion among concrete design and construction professionals. This project aims to bring unified guidance concerning chloride ion limits, freezing-and-thawing performance, and external sulfate attack for ACI documents.

"The best way to address concrete durability in specifications and guidance documents is a source of controversy," states Jason Ideker, one of the project's principal investigators. "The results of this research will provide recommendations on unified durability specifications and exposure category descriptions to ACI committees. This will provide a strong foundation for document revision."

The project's goal of bringing congruent information concerning these limits and requirements will be accomplished by rigorous statistical analysis of existing data from field exposure sites, published literature, and laboratory testing. This data analysis will provide evidence-based results that will inform relevant ACI committees on how to establish unified guidance leading to the solution of the current document discrepancies.

The research for this project is estimated to be completed in just over 1 year once analysis begins. The project comprises five stages:

1. Create an industry advisory board;
2. Procure and organize all relevant data from existing literature, laboratory testing, and field exposure sites;
3. Perform the statistical analysis of the organized data;
4. Establish the recommended specification indicators; and
5. Assess the recommended specification indicators.

The principal investigators are Jason Ideker, Oregon State University; Kimberly Kurtis, Georgia Institute of Technology; Michael Thomas, University of New Brunswick; and Anthony Bentivegna, CTLGroup. ACI 201, 222, 318, and 350-B comprise the supporting committees and subcommittee; the project also received industry support from the U.S. Army Corps of Engineers.

Concrete 2029 Continues Building to the Future

The ACI Foundation's Strategic Development Council (SDC) is facilitating the development of Concrete 2029, a strategy and plan for the improvement of the concrete construction industry. An initial workshop for Concrete 2029 was held May 10, 2016, in San Antonio, TX, immediately preceding SDC's Technology Forum #39. Sponsored by the SDC and the American Society of Concrete Contractors (ASCC) and moderated by Peter Emmons, President of the ASCC Foundation and Founder and CEO of STRUCTURAL Group, Columbia, MD, the event focused on issues such as defining and improving in-place concrete quality, workplace productivity, and industry promotion and perception. Presentation topics included:

- The Misconstrued Image of Concrete;
- The Owner's Mindset;
- Consequences of Poor Design;
- What Must Happen to Improve Productivity; and
- Attracting and Training the Right People.

These topics were selected by the Concrete 2029 planning team to take into consideration multiple viewpoints, including those of contractors, designers, and owners, with the goal of moving the entire concrete construction industry forward. Over 65 individuals, representing a broad cross section of the industry, attended the initial workshop—underscoring the importance of Concrete 2029's place in planning for the future of the concrete construction industry.

Following the initial presentations, workshop attendees met as smaller (breakout) groups to analyze the strengths, weaknesses, opportunities, and threats (SWOT) faced by the concrete industry. Specific themes for the breakout groups included contractor certification, the construction workforce, durability assessment of materials and systems, productivity, and image of the industry. While technology was not a separate theme, it was included in every discussion, particularly as it relates to improvement of the industry's quality, productivity, or image. The breakout groups then presented their findings to the full workshop.

The Concrete 2029 planning team has since refined the findings of Workshop 1, and the SDC has announced a second workshop. This event will further define and prioritize the goals for populating a roadmap for the concrete construction industry. "The industry has pulled together to identify the trends that are affecting it," stated Doug Sordyl, Managing Director of the SDC. "Continued vigilance and unified industry action can turn our challenges into an immense opportunity."

Concrete 2029 Workshop 2 is scheduled for September 7, 2016, in Salt Lake City, UT, preceding SDC's Technology Forum #40. Registration information for the upcoming Concrete 2029 workshop, as well as the presentations and agenda from the first workshop, are available at **www.ConcreteSDC.org**.

2029 Planning Team

- Nick Adams, The Euclid Chemical Company
- Scott Anderson, Keystone Structural Concrete, LLC
- Ann Daugherty, ACI Foundation
- Peter Emmons, STRUCTURAL
- Bev Garnant, American Society of Concrete Contractors
- John Hausfeld, Baker Concrete Construction, Inc.
- Bill Palmer, Hanley Wood, LLC
- Bill Phelan, The Euclid Chemical Company
- Chris Plue, Webcor Builders
- Doug Sordyl, Strategic Development Council

Stehly Memorial Hockey Game is a Tremendous Success

The fourth annual installment of the Richard D. Stehly Memorial Hockey Game raised over $2350 for the Richard D. Stehly Memorial Scholarship. "I really want to thank everyone who came out to watch, skate, and donate," said Larry Sutter, the organizer of this year's game, "Especially, I want to mention the support this game received from the local Wisconsin ACI Chapter; without their help in organizing the logistics of this event, it would not have been possible."

The latest Richard D. Stehly Memorial Hockey Game took place during The ACI Concrete Convention and Exposition in Milwaukee, WI, this past April. ACI members and staff comprised the rosters of the two competing teams. The fifth installment of the Richard D. Stehly Memorial Hockey Game is being planned for next year's spring ACI Convention, March 26-30, 2017, in Detroit, MI. Sutter hopes that the Richard D. Stehly Memorial Hockey Game becomes an annual tradition with the hosting chapter competing to better the fundraising efforts of the previous hosting chapter; all funds go to support the Richard D. Stehly Memorial Scholarship.

Richard (Dick) Stehly had been a member of ACI since 1980 and was elected President in 2010. He believed that attracting and educating ACI's youngest members was crucial for both the future of the concrete industry and ACI. His conviction for investing in ACI's posterity led him to bequeath a portion of his estate to fund future ACI scholarships and fellowships. Stehly personally organized the first two editions of this hockey game before his passing. The game was then memorialized in his honor. "It was very much in Dick's character to quietly organize things like this game," said Sutter. "Once Dick passed, the Minnesota Chapter and now the Wisconsin Chapter stepped up to honor Dick and raise money for his scholarship."

The Richard D. Stehly Scholarship is awarded annually through the ACI Foundation to an outstanding student enrolled in an undergraduate degree program studying concrete with an emphasis on structural design, materials, or construction. More information about the Foundation's Fellowships and Scholarships can be found at **www.ACIFoundation.org**.

ACI members and staff pose for a team picture before the Richard D. Stehly Memorial Hockey Game

Slag Cement Association 2015 Project of the Year Awards

The Slag Cement Association (SCA) presented the 2015 Project of the Year Awards on April 18, 2016, during the Technical Session, "Use of Slag Cement in Notable Structures, Part 2," at The ACI Concrete Convention and Exposition – Spring 2016, in Milwaukee, WI. The awards recognize projects for excellence and innovation in concrete using slag cement. Nine projects received 2015 Awards in the categories of Architectural Design, Durability, Green Design, High Performance, Innovative Applications, and Sustainability.

Architectural Design

Children's Hospital of Richmond

Children's Hospital of Richmond at Virginia Commonwealth University (VCU) is a multi-story, 640,000 ft^2 (59,500 m^2), high-tech outpatient pavilion for pediatric services. As an oasis for children, the new space features a James River theme incorporating naturalistic elements of light and green space.

Slag cement was used at 60% of total cementitious material content for the 11,000 yd^3 (8400 m^3) of mass concrete in the mat foundation. Slag cement was also used at 40% in 3500 psi (24 MPa) pumped structural lightweight concrete and in low-permeability, 5000 psi (35 MPa) pumped structural concrete for the parking garage. Mass concrete specifications required strengths of 5000 and 7000 psi (48 MPa) and included maximum and differential temperature limits of 160 and 35°F (71 and 19°C), respectively. The mixture needed to have a self-consolidating consistency to move through 6 to 7 ft (1.8 to 2.1 m) of congested reinforcement with limited external consolidation. Concrete was placed in four placements using three concrete plants to supply the required 300 to 400 yd^3/h (229 to 305 m^3/h) within the time constraints of driver hours of service regulations and downtown overnight road closures. All concrete met 28-day strength requirements, temperature specifications, and not a single load was lost due to delivered quality.

Project credits: Children's Hospital of Richmond at Virginia Commonwealth University, Owner; HKS, Inc., Architect; Dunbar, Milby, Williams, Pittman & Vaughan, PLLC, Engineer; Skanska USA Building, Inc., Construction Manager; Cleveland Cement Contractors, Contractor; Vulcan Materials Company, Concrete; and LafargeHolcim, Slag Cement.

Children's Hospital of Richmond, VA, at VCU

Jade Signature

Designed by architects Herzog & De Meuron, Jade Signature in Sunny Isle Beach, FL, provides an inspiring example of architectural use of concrete to create a unique living space in this beautiful beachfront environment. Slag cement was used in deep soil mixing, the mat foundation, and the superstructure.

Deep soil mixing allowed for the efficient construction of the belowground parking area. The in-place soil was mixed with a slag cement:portland cement slurry that contained 80 to 90% slag cement. This mixture proportion was used to solidify the entire base of the project and allowed for the parking garage to be constructed in very difficult, high water table conditions.

Rendering of Jade Signature, Sunny Isle Beach, FL

The mat foundation required high-strength, 10,000 psi (69 MPa) mass concrete with 60% slag cement. The 9800 yd^3 (7500 m^3) of mass concrete was placed in 18 hours. In the superstructure, virtually all of the concrete contains slag cement used at between 50 and 60% to achieve specified strengths from 3000 to 8500 psi (21 to 59 MPa), depending on the application.

Project credits: Fortune International Group, Owner; Herzog & De Meuron, Architect; McNamara/Salvia, Inc., Malcolm Drilling, and Capform, Inc., Contractors; Supermix Concrete, Concrete; and Lehigh Cement Company, Slag Cement.

Durability

Arlington River Bridge on University Boulevard

The Arlington River Bridge on University Boulevard in Jacksonville, FL, replaced an aging bridge with a new two-lane concrete bridge that has 6.5 ft (1.9 m) wide sidewalks, 4 ft (1.2 m) wide bicycle lanes, decorative lighting, and architectural railings. The Florida Department of Transportation (FDOT) required uninterrupted vehicular traffic and pedestrian access to the mainland and continued marine traffic during construction. Therefore, the project entailed construction of a temporary bridge, demolition of the existing bridge, construction of the new permanent bridge, and removal of the temporary bridge.

To enhance sustainability and durability in this saltwater environment exposed to constant tidal action, 60% slag cement was used in a ternary concrete mixture with 30% portland cement and 10% fly ash. Used in the bridge deck as well as the architectural railing, this concrete mixture design exceeded FDOT's specified surface resistivity criteria and strength requirements. Durability and strength objectives were achieved at a reduced environmental footprint because slag cement is a recycled material. Slag cement provided consistent concrete performance and a lighter color concrete.

Project credits: Florida Department of Transportation, Owner; Parsons Transportation Company, Civil Engineer Consultant; Aracadis, Engineer; Superior Construction Company, Contractor; Argos Ready Mix, LLC, Concrete; and Argos USA, Slag Cement.

Arlington River Bridge on University Boulevard, Jacksonville, FL

City of Clyde Waste Water Treatment Plant Flow Equalization Basin

The City of Clyde, OH, installed a 1 million gal. (118,000 L) flow equalization basin at the city's wastewater treatment plant. The basin's inside dimensions measure 120 ft long x 100 ft wide x 14 ft deep (36 x 30 x 4.2 m). During high incoming flow events, excess flow is screened in the combined sewer overflow (CSO) diversion chamber and is directed to the basin by gravity. Plant personnel can drain the basin by gravity using the plant's supervisory control and data acquisition (SCADA) system. An automated tipping bucket flushing system is used to flush accumulated solids and debris from the basin floor.

The monolithic placement of a 1950 yd^3 (1300 m^3) mat foundation for the bottom of the equalization basin was 4 ft thick x 105 ft wide x 125 ft long (1.2 x 32 x 38 m). Slag cement helped reduce thermal stress in the mass concrete. Slag cement was used at a 40% replacement level in the mat foundation basin floor and at a 25% replacement in basin walls. The aggressive environment this wastewater treatment application entails requires a durable concrete. Use of slag cement in basin floor and walls met specified strength criteria, provided desired sulfate resistance, reduced permeability, and reduced susceptibility to alkali-silica reaction (ASR).

Project credits: City of Clyde, OH, Owner; GGJ, Inc., Engineer; Adena Corporation, Contractor; Huron Cement Products Co., Inc., Concrete; and St Marys Cement Inc. (U.S.), Slag Cement.

Wastewater Treatment Plant Flow Equalization Basin, Clyde, OH

Green Design

Heritage Cooperative Agricultural Campus and Research Farm

The Heritage Cooperative Agricultural Campus and Research Farm in Marysville, OH, is built on a 277 acre (112 ha) site. It includes an express unit grain terminal, which holds 1.5 million bushels of grain; a 30,000 ton (27,000 tonne) dry fertilizer warehouse; and a 10,000 ton (9000 tonne) liquid nitrogen fertilizer storage with distribution services 24 hours a day, 7 days a week. Over 20,000 yd^3 (15,000 m^3) of concrete, with nearly all of it containing slag cement, was used—including 5600 yd^3 (4300 m^3) for slipformed silos that took 7 days to complete, working 24 hours per day.

The wall forms were on a timer and moved 1 in. (25 mm) every 4 to 6 minutes. Consistent stiffness and setting time were needed to maintain that pace of construction. The slag cement concrete mixture actually allowed the contractor to speed up the slipform construction process. Prior to construction, the owner was concerned that they would have to paint the silos to achieve desired uniformity in color. However, the slag cement concrete mixture provided an attractive, uniform, light color without painting.

Project credits: Heritage Cooperative, Owner; Hogenson Construction Company, Architect; Sunfield Engineering, Engineer; Hogenson Construction Company, Contractor; Ohio Ready Mix, Inc., Concrete Supplier; and St Marys Cement Inc. (U.S.), Slag Cement.

Heritage Cooperative Agricultural Campus and Research Farm, Marysville, OH

Tilikum Crossing Bridge

At 1700 ft (518 m) in length, Tilikum Crossing, in Portland, OR, is referred to as the "Bridge of the People," and is the first bridge of its kind in the United States. A cable-stayed bridge, with two piers in the water and two on land, Tilikum Crossing is designed to carry light-rail trains, buses, street cars, cyclists, and pedestrians, but not automobiles.

Slag cement was used in the high-performance concrete on the bridge to increase durability. The mixture proportions for the girder sections required 3500 psi (24 MPa) at 18 hours and 8000 psi (55 MPa) in 56 days. There were no low strength tests on this project. The mass concrete contained 50% slag cement to lower heat of hydration. The use of slag cement contributed to achieving the lighter color desired by the designer without using white cement. The reliable supply and performance of slag cement consistently provided specified concrete plastic properties. In addition, use of slag cement reduced the carbon footprint of the project, contributing to achieving the desired green design, sustainable development objectives for this mass-transit centered structure.

Tilikum Crossing Bridge, Portland, OR

432 Park Avenue, New York, NY *(photo courtesy of Citizen59, Wikimedia Commons)*

Project credits: TriMet, Owner; Donald McDonald Architects, Architect; T.Y. Lin International Group, Engineer; Kiewit Infrastructure West Co., Contractor; Ross Island Sand & Gravel, Concrete; and Ash Grove Cement Company, Slag Cement.

High Performance

432 Park Avenue

Topping out at 1396 ft (425 m), 432 Park Avenue, New York, NY, is the tallest residential building in the Western Hemisphere. While 432 Park Avenue is second in overall height to One World Trade Center, it is the tallest building in New York City when measured from rooftop height. The structure is reinforced cast-in-place concrete. Architecturally exposed white concrete columns and a central shear wall core support the building. Other than its height, this building is unique due to its slenderness ratio of 15:1.

To provide the required concrete performance for the structural design, 14,000 psi (97 MPa) concrete was specified for the foundation and part of the superstructure. High-performance concrete criteria included heat reduction in the mass concrete placements, high strength for structural performance, superior rheology for pumping concrete, and a reduced environmental footprint to achieve sustainable design objectives. A high-performance concrete mixture, with a cementitious material content of 55% slag cement, 30% portland cement, 11% fly ash, and 4% silica fume, was developed to meet demanding specification and construction requirements. Laboratory strengths of over 18,000 psi (124 MPa) were achieved with this mixture. This high-performance concrete design represents a new era of building design where optimizing the use of supplementary cementitious materials (SCMs) can enable the construction of tall slender buildings in large cities with scarce and valuable lot space.

Project credits: McGraw Hudson, Owner; SLCE Architects, Architect; WSP Global, Engineer; Lend Lease, Contractor; Jenna Concrete, Concrete (foundation), Ferrara Brothers Concrete, Concrete (superstructure); and LafargeHolcim, Slag Cement.

Innovative Applications

I-79/I-70 South Junction

The I-79/I-70 South Junction Interchange Improvement Project in South Strabane Township, Washington County, PA, eliminated a severely curved connector ramp and replaced it with a large nine-span flyover bridge and new ramp system. The existing curved ramp had been the site of numerous accidents.

To improve safety, an innovative box culvert redesign alternative to the "as-designed" rehabilitation of the two mainline bridges carrying I-70 over the ramp to I-79 South eliminated the requirement for mainline crossovers on a curve during reconstruction. This innovative alternative solution not only enhanced construction efficiency but it also improved traffic flow and safety during construction and simplified future planned mainline reconstruction of I-70.

Innovative design and construction solutions were complemented by use of slag cement at a 50% replacement level in both self-consolidating concrete (SCC) and mass concrete mixtures. SCC was used for drilled shafts, while mass concrete was defined as any concrete element with a minimum dimension of 6 ft (1.8 m) or greater, including drilled shafts and pier caps. The 50% slag cement mass concrete mixture aided in meeting the thermal control plan for mass concrete placements and allowed discontinuing temperature monitoring of mass concrete elements earlier than expected. The 50% SCC mixture met specified flow, penetration, segregation resistance, visual stability index, strength, permeability, and freezing-and-thawing durability performance requirements.

Project credits: Pennsylvania Department of Transportation, Owner; HDR Engineering, Project Engineer; Mackin Engineering, Engineer (culvert redesign); Golden Triangle Construction, Contractor; Golden Triangle Construction, Concrete; and Essroc Italcementi Group, Slag Cement.

Sustainability

JFK International Airport Runway 4L-22R Reconstruction

The $267 million Runway 4L-22R Runway Safety Compliance and Reconstruction Project, at JFK International Airport, New York, NY, consisted of rehabilitating the existing asphalt runway with a concrete overlay. The existing runway was milled approximately 6 in. (150 mm) deep; then a 2 in. (50 mm) leveling course of asphalt was used prior to the placement of the 18 in. (454 mm) concrete overlay. A full-depth 18 in. concrete pavement was used to widen the runway by 50 ft (15 m) and add an extension of 700 ft (212 m) for a final 12,700 x 200 ft (3900 x 61 m) runway with 40 ft (12 m) wide shoulders. This rehabilitation and widening project enhances the efficiency of the airport and 4L-22R will handle about 25% percent of the annual operations.

Concrete specifications for this project required a minimum flexural strength of 700 psi (5 MPa) at 28 days with a maximum cementitious material content of 550 lb/yd^3 (296 kg/m^3). The specifications also required a low chloride permeability as measured by the rapid chloride permeability test. The Port Authority Materials division recommended using slag cement as part of the mixture proportions because slag cement increases flexural strengths, reduces the concrete permeability, and makes the concrete more resistant to ASR. To achieve the concrete pavement slipform construction requirements and meet the contract specifications, a Type IS (40) cement was used in the concrete mixture. ASTM C595/C595M Type IS (40) designates a portland blast-furnace slag cement that contains 40% slag. Laboratory mixture proportion testing yielded a 28-day flexural strength of 1300 psi (9 MPa). This concrete mixture met performance requirements for constructibility, strength, durability, and smoothness—all at a reduced environmental impact.

Project credits: Port Authority of New York and New Jersey, Owner; Port Authority of New York and New Jersey – Materials Division, Engineer; Tutor Perini Corporation, Contractor and Concrete; and Lehigh Cement Company, Slag Cement.

SCA represents companies that produce and ship over 90% of the slag cement (ground-granulated blast-furnace slag) in the United States. Through a program of promotion, education, and technology development, SCA communicates the performance and sustainable benefits of this cementitious material to stakeholders throughout the construction industry. More information is available at **www.slagcement.org**.

I-79/I-70 South Junction Interchange, Washington County, PA

JFK International Airport – Runway 4L-22R Reconstruction, New York, NY

photo courtesy of J. Fusco for VISIT PHILADELPHIA™

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Higher Wind Towers on the Rise

Post-tensioned segmental technology allows record heights and efficiencies

by James D. Lockwood, Matthew J. Chase, and Steven T. McRory

A U.S. record high wind tower, with a hub height of 115 m (377 ft), was recently commissioned in Adams County, IA. The patented tower system was developed by Siemens Wind Power in partnership with Wind Tower Technologies (WTT) of Boulder, CO, using the precast segmental construction method. Precast segmental construction has proven to be highly competitive in the bridge industry on large viaducts—projects in which standardization is common. The new tower system is fabricated on site, eliminating the disruptions and costs inherent with transporting large steel tower sections over roads and bridges from remote locations to the project site. Using on-site concrete fabrication, the tower base diameter is nearly unrestricted, thereby allowing tower heights to be limited only by zoning permits and erection equipment.

According to Luis Carbonell, Civil Engineering Manager of Siemens, the segmental concrete technology provides their company an opportunity to introduce a new tower concept from the ground up that is aligned with the company's market strategy.

The market size projection for utility-scale wind energy production in the United States is estimated to exceed 47 GW over the next 5 years, resulting in the projected installation of over 17,000 new towers in steel and concrete in this period. This creates a large opportunity for the concrete industry to compete in this growth market.

The significance of taller towers is higher energy production in many geographic markets where increased wind speeds exist with height. The market opportunity for concrete wind towers in North and South America is high as the wind market trends toward taller towers.

The ACI Foundation invites you to learn more about concrete's always advancing role with wind turbine towers at the Strategic Development Council's Technology Forum #40. The Forum will feature presentations concerning concrete and wind turbine towers on September 8-9, 2016, at the DoubleTree Salt Lake City Airport Hotel, Salt Lake City, UT. Register at ***www.ConcreteSDC.org****.*

On-site Tower Segment Casting

One contributing challenge in the wind industry today is transporting large steel tubular sections. Transportation costs of steel towers are high, and clearance restrictions on state department of transportation (DOT) highways and bridges limit the diameter of the lower sections of the tower and thus the height of the tower. This can only be overcome using heavier steel wall sections or high-strength steel, and each of these are less cost effective than increasing the diameter of the base. As the industry grows and new geographic markets develop, higher hub heights, well above 100 m (328 ft), are more desirable and improve the cost benefits of on-site precast towers.

115 m precast concrete wind tower with 108 m (354 ft) rotor

On-site precasting of the tower segments not only removes limitations on the diameter of the tower base and corresponding height but it also allows the use of local labor and locally sourced materials such as reinforcing steel, aggregates, cement, and admixtures. Further cost-saving opportunities are offered when the foundation contractor and concrete tower contractor can coordinate sourcing of materials from the same batch plant.

To achieve the required speed of construction, the concrete tower segments are match cast together, resulting in a tight fit between segments when installed. The geometry of the tower is therefore largely set in the casting yard with minor provisions for alignment adjustments during erection.

Formwork installed in precast yard to match-cast next segment

Concrete finishing of segment joint in preparation for next casting

Finished segments in storage ready for installation into the tower

Technology Transfer

The technology of precast segmental construction involves match-casting one segment against the next in series. When assembled and post-tensioned together during erection, a continuous structure is created. This construction method has evolved to be very competitive in the bridge industry on larger projects that lend themselves to an industrialized, on-site construction method. The repetitive nature of wind towers on an individual wind farm lends itself very well to this industrialized on-site manufacturing approach.

Precast segmental bridge construction using match-cast joints

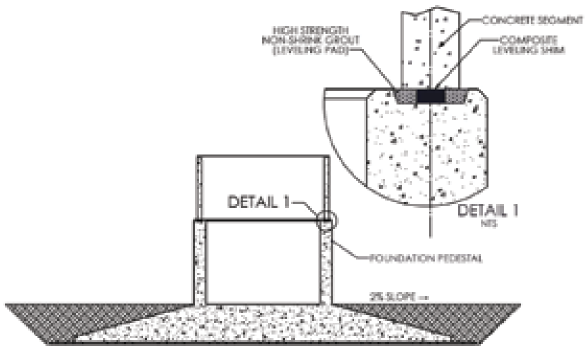
Cast-in-Place Foundation

The cast-in-place foundation for the Siemens precast tower incorporates an annular pedestal wall that enables the precast tower to connect to the foundation using a grouted joint that provides a uniform transfer of forces. The connection, located close to ground level, is the only grouted joint in the tower. By separating the cast-in-place foundation activities from the precast tower activities, the project owner maintains the flexibility of negotiating the foundation construction contact separate from the tower construction contract.

The Siemens concrete tower foundation is similar to that used for a steel wind tower foundation; however, because the concrete tower weight exceeds that of a steel tower for the equivalent load carrying capacity, the foundation quantities for a concrete tower can be reduced in comparison to the

Cast-in-place foundation placed prior to casting pedestal wall and backfilling with soil

foundation quantities needed for a steel tower. The precast tower system is installed onto the foundation's pedestal wall and secured to the foundation using post-tensioning. This connection has benefits over steel tower connections, whereby mechanical anchor bolts extend through steel flange plates, reducing future maintenance of these mechanical components.



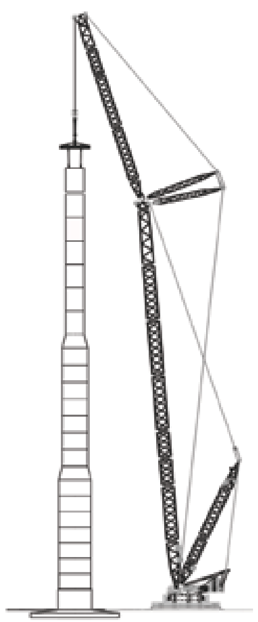
Foundation to pedestal wall schematic

The first known utility scale wind tower in production was the TVINDkraft tower in Denmark in 1975, constructed using cast-in-place concrete. Since that project, the European wind power market has evolved toward manufacturing and transportation of steel tower sections bolted together on site. This solution was transferred to the Americas over the past 20 years. With wind towers increasing in height and carrying larger rotors and turbines, innovative concrete tower designs and construction techniques are becoming increasingly important.

The precast segmental tower solution may change the wind industry's landscape. During the development of the system, the importance of speed in construction of the wind towers was critical. The use of match-casting to eliminate grouting of the joints during segment stacking is an important differentiator in constructing the concrete tower.

The concrete tower is stepped to optimize the use of formwork. The transition from concrete to steel near the top of the tower allows for a standardized steel top section for the yaw attachment and cabling platforms.

Precast segment lifted by crane for placement onto the tower



Schematic of tower erection

Precast segments fully stacked and post-tensioned to foundation

Project Credits

Testing and construction

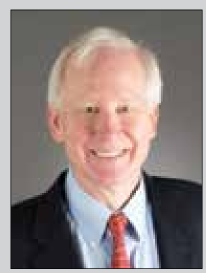
Full-scale fabrication and testing of the tower sections were completed in early 2015. These activities were followed by the construction of a fully operational turbine tower in Iowa, both constructed by Baker RD Concrete Construction, Clovis, NM. EFCO Forms, Des Moines, IA, provided formwork to Siemens for casting the tower segments. Schwager Davis, Inc., San Jose, CA, supplied and installed post-tensioning for the turbine tower constructed in Iowa.

Technical team

The technical team was assembled from a group of experienced professionals with expertise in precast segmental bridge design and construction, large utility scale tower engineering, and the knowledge of wind farm logistics and schedule requirements. Principals included Siemens Wind Power Americas—Luis Carbonell, Steven McRory, and Francisco Morales; and Wind Tower Technologies—Jim Lockwood, Matt Chase, and Panos Kiousis. The Peer Review team comprised Thornton Tomasetti, Chicago, IL, and Denver, CO; and International Bridge Technologies, San Diego, CA.

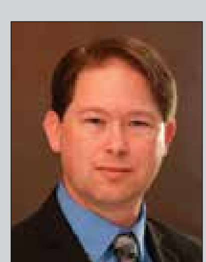
Selected for reader interest by the editors.

From left: Matt Chase, Steven McRory, and Jim Lockwood inspecting formwork prior to the next concrete placement



ACI member **James D. Lockwood** is the CEO and founder of Wind Tower Technologies, Boulder, CO. He has over 30 years of experience in structural engineering, product development, and design/build projects. Lockwood has worked 15 years in the field of precast segmental bridge design and construction with Figg & Muller Engineers and Jean Muller International (JMI). During his tenure with JMI, he established and managed JMI's Chicago and New York City offices. Lockwood received his BSCE from the University of Cincinnati, Cincinnati, OH, and his MSCE from the University of Washington, Seattle, WA. He is a licensed professional engineer.

Matthew J. Chase is the Director of Wind Tower Technologies. As a structural engineer, his relevant design experience dates back to 2006. Over the past 8 years, Chase has designed and been involved in the construction of wind towers and wind tower foundations for industrial-scale wind farm projects around the world. He received his bachelor's degree from the University of Wyoming, Laramie, WY. He is a licensed professional engineer in 10 states, a member of the American Society of Civil Engineers (ASCE), and a contributing member of IEC PT06 Concrete Group.



Steven T. McRory is a Principal Engineer at Siemens Energy, Inc., Orlando, FL. As a structural engineer, his design experience dates back to 2005. Over the past 11 years, he has designed and been involved in the construction of bridges, major infrastructure projects, wind turbine towers, and wind turbine foundations. McRory received his bachelor's and master's degrees from the University of Central Florida, Orlando, FL. He is a licensed professional engineer.

Effect of Cold Curing Water on Concrete

Experiments confirm inelastic, not elastic, approach valid

by Ronald L. Kozikowski, Heather J. Brown, Ward R. Malisch, and Bruce A. Suprenant

Section 3.2 of ACI 308R-16, "Guide to External Curing of Concrete,"[1] states: "Curing water should not be more than 20°F (11°C) cooler than the internal concrete temperature to minimize stresses due to temperature gradients that could cause cracking (Kosmatka and Wilson 2011[2]). A sudden drop in concrete temperature of approximately 20°F (11°C) can produce a strain of approximately 100 millionths, which approximates the typical strain capacity of concrete (Mather 1987[3]) beyond which the concrete may crack."

ACI 308R-16 does not cite any data or calculations to support the statement that a sudden drop in concrete temperature of about 20°F can produce a strain of about 100 millionths. Also, Kosmatka and Wilson[2] suggest only that: "The curing water should not be more than about 11°C (20°F) cooler than the concrete to prevent thermal stresses that result in cracking." They do not discuss how a 20°F concrete temperature drop produces a strain of about 100 millionths. Also, the committee apparently misinterpreted Mather's paper,[3] in which he cited an anonymous report that stated, in concept, that "…the use of water [curing] leads to severe superficial cooling, resulting from the marked evaporation due to the strong winds, which introduces a steep temperature gradient in the fresh concrete and may increase the risk of surface cracking." But neither Mather's paper nor the anonymous report provides any information on the temperature gradient induced by such evaporation or strain capacity at which cracking might occur.

We also traced the 20°F value as far back as ACI 308-71, "Recommended Practice for Curing Concrete"[4]:

"2.2.1 *Ponding or immersion*—…Curing water should not be more than about 20 F (11 C) cooler than the concrete, because of temperature-change stresses which would be introduced with resultant cracking."

Again, the origins of this maximum 20°F temperature difference between the curing water and concrete surface are not apparent. Because the document provides no analysis or data to support the 20°F temperature difference, the authors developed elastic and inelastic analyses and conducted two experiments to evaluate the validity of ACI recommendations. These are discussed in the following sections.

Elastic Analysis of Effect of Temperature Drop

We believe the rationale for the mentioned 20°F limit is based on an elastic analysis. In the following analyses, we use in.-lb units because the original derivation would have been in those units. However, similar conclusions would be obtained using SI units.

Thermal contraction

The elastic strain for unrestrained thermal contraction would be calculated as the product of the coefficient of thermal expansion and the temperature change. Section 2.9.1 of ACI 209R-92(08), "Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures,"[5] suggests using a coefficient of thermal expansion of 5.5×10^{-6}/°F. Using this value and multiplying by 20°F yields a strain of 110 millionths, in general agreement with the ACI 308R-16 statement that associates a 20°F temperature difference with a strain of "approximately 100 millionths."

Strain capacity

We can calculate the "typical strain capacity of concrete" by using Hooke's Law and assuming complete restraint. In other words, the strain capacity is the quotient of the tensile strength and the modulus of elasticity E_c. The tensile strength of concrete is often assumed to be about 10% of the concrete compressive strength. If we assume a compressive strength of 3000 psi, the tensile strength would be about 300 psi. ACI Committee 318[6] permits E_c for normalweight concrete to be estimated using $E_c = 57{,}000\sqrt{f_c'}$.

For 3000 psi concrete, E_c is thus about 3.1×10^6 psi, and the typical elastic strain capacity would be about $300/3.1 \times 10^6 =$ 97 millionths. Again, this is "approximately 100 millionths."

The two calculations appear to be the bases for stating that a sudden drop in concrete temperature of about 20°F can produce a strain of about "100 millionths, which approximates the typical strain capacity of concrete." This approach leads to very conservative

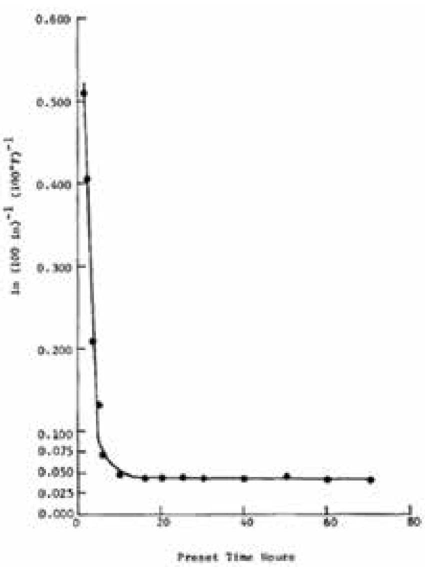


Fig. 1: The coefficient of thermal expansion is highest for fresh concrete and then decreases when the concrete sets (Fig. 5.2.5.2 in ACI 517.2R-80[8])

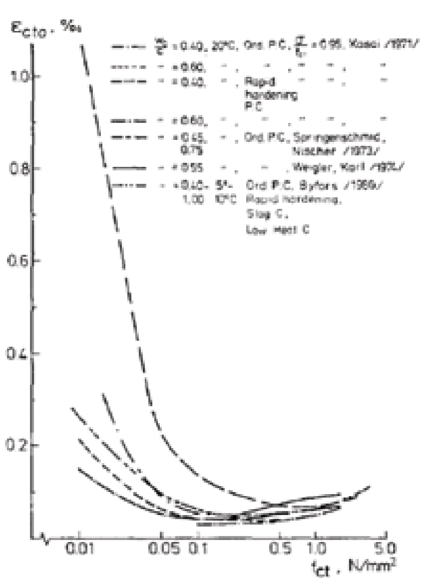


Fig. 2: Strain capacity versus age of concrete, at 95% of tensile strength (from Byfors[12])

values because the concrete is only about 4 to 12 hours old when curing water is applied, and at this early age it will exhibit elastic and inelastic behavior. Further, water added to the concrete surface will not cause the "sudden [instantaneous] drop in concrete temperature" needed to result in the assumed elastic behavior.

To calculate the maximum temperature difference between curing water and a concrete surface that *might* cause cracking, an analytical approach assuming inelastic behavior should be used. Alternatively, a simple field test can be used to test the validity of the elastic and inelastic approaches.

Inelastic Analysis for Effect of Temperature Drop

Curing water is applied to concrete after final finishing when the application of the water and workers walking on the concrete will not mar the surface. In hot weather, this might occur only 3 to 4 hours after placement. In colder weather, final finishing might be as much as 8 to 10 hours after placement. In cold weather, though, ACI 306R-10, "Guide to Cold Weather Concreting"[7] (Section 10.2), recommends that water curing not be used. The coefficient of thermal expansion and strain capacity (tensile strength divided by the modulus of elasticity) are both time dependent at early ages. Thus, we need to find suitable values based on the age of the concrete.

Coefficient of thermal expansion

The coefficient of thermal expansion for concrete is highest when a mixture is fresh (Fig. 1) and then decreases when the mixture sets.[8-10] The coefficient of thermal expansion could be about 5.5×10^{-6}/°F at the time curing water is added to the concrete surface. Hammer,[11] however, reported lower values—as low as 3.5×10^{-6}/°F—for concrete used in his experiments. It would appear that using the ACI 209R-92(08) recommended value of 5.5×10^{-6}/°F for hardened concrete is reasonable for early-age concrete that has set enough so that curing water placed on the surface doesn't damage it.

Strain capacity

Tensile strain capacity of early-age concrete has been measured by a number of investigators in a RILEM report.[10] This report states: "We should note that the ultimate strain assumes a minimum value as low as 0.05% at approximately the tensile strength of 0.2 N/mm² [30 psi]." Byfors[12] summarized the work of others (Fig. 2) and plotted strain capacity versus age at 95% of tensile strength. These data indicate a minimum strain capacity of about 0.04% at about 5 to 6 hours. Kasai et al.[13] measured the tensile strain capacity for six different types of concrete with two different water-cement ratios (*w*/*c*) and two slumps. He also found the strain capacity to be about 0.05% (Fig. 3). In his review of other investigators' work, Hammer[11] also indicated that the minimum strain capacity of early-age concrete to be about 0.05% (500×10^{-6} in./in.).

Maximum temperature difference based on measured strain capacity

If we use a coefficient of thermal expansion of 5.5×10^{-6}/°F and a tensile strain capacity of 500×10^{-6} in./in., the calculated maximum temperature difference between the cold curing water and warmer concrete would be 90°F (32°C). Certainly, this is a significant increase from the 20°F calculated using the elastic approach. But we should also consider other factors, such as a reduction in strain capacity due to drying and strain rate.

Reduction in tensile strain capacity due to strain rate

Kasai et al.[14] measured the tensile strain capacity of two different concrete mixtures with *w*/*c* of 0.40 and 0.60 at three different strain rates by using load durations of 5, 60, and 90 minutes up to failure (Fig. 4). The specimens loaded at slower loading rates showed a greater tensile strain capacity. The minimum tensile strain capacity for the 5-minute loading until failure was about 0.03%. Thus, it's clear that strain rate can significantly influence the

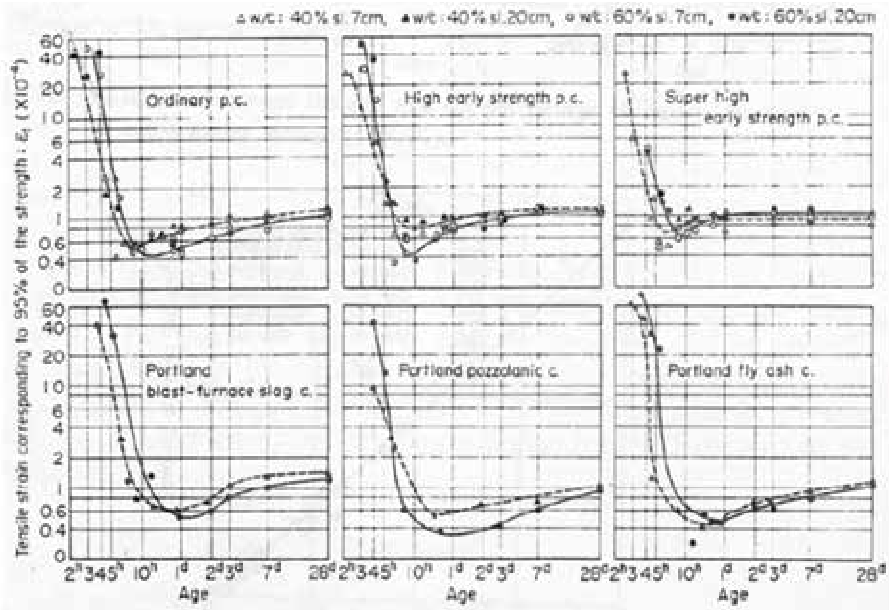


Fig. 3: Tensile strain capacity for six different types of concrete with *w/c* values of 0.4 and 0.6 and slumps of 70 and 200 mm (from Kasai et al.[14])

tensile strain capacity used to calculate the maximum temperature difference between the curing water and concrete surface.

Of course, the important question is: When the curing water is added to the top concrete surface after finishing, at what strain rate does the curing water temperature difference affect the concrete surface? If we assume that the curing water temperature difference will affect the concrete surface in 5 minutes, we can recalculate the maximum temperature difference using a thermal coefficient of expansion of 5.5×10^{-6}/°F and a tensile strain capacity of 300×10^{-6} in./in. Under these assumptions, the maximum temperature difference between the curing water and the concrete should be 55°F (31°C).

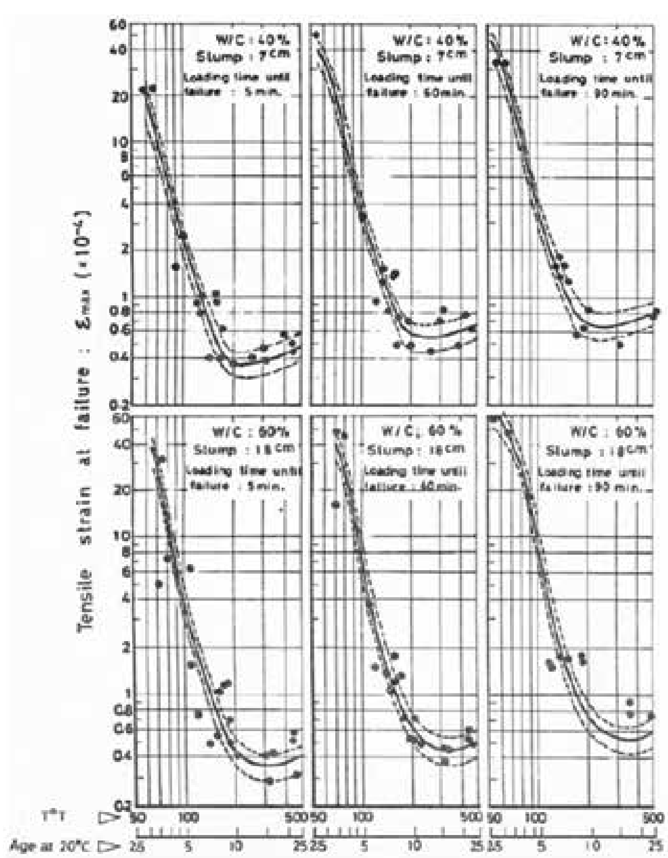


Fig. 4: Tensile strain capacity of two different types of concrete with *w/c* values of 0.40 and 0.60 at three different strain rates by using load durations of 5, 60, and 90 minutes up to failure (from Kasai et al.[15])

Reduction in tensile strain capacity due to external drying

We agree with Hammer[11] that external drying reduces the tensile strain capacity of early-age concrete. Although we expect only a little moisture loss during the short drying period, that external drying could create a moisture gradient that could contribute to shrinkage strains and a reduction of the subsequent strain capacity at the time of contact with cold curing water. Thus, drying shrinkage strains due to evaporation prior to addition of curing water would be additive to temperature strains due to contraction caused by the cooler curing water.

What to Do Now?

Based on various assumptions, we have calculated that the temperature difference between the curing water and concrete surface ranging from 20 to 90°F may cause cracking, as shown in Table 1. Given the wide range, we decided to conduct tests.

Table 1:

Summary of elastic and inelastic analyses used to calculate temperature difference between curing water and concrete surface that can cause cracking

Assumption	Strain capacity, $\times 10^{-6}$ in./in.	Maximum difference in curing water and concrete temperature, °F
Elastic model	100	20
Inelastic model	500	90
Inelastic with strain rate	300	55

Fig. 5: Test slabs were constructed using 2 x 3 ft x 5-1/2 in. deep (610 x 915 x 140 mm) forms containing thermistors spaced at different depths (1/8, 1/4, 1/2, 1, and 2-1/2 in. [3.2, 6.4, 12.7, 25.4, and 63.5 mm]) from the top

Testing

Fast and simple—Middle Tennessee State University (MTSU)

The MTSU tests[15] consisted of two, 2 ft (610 mm) square slabs: one 5-1/4 in. (133 mm) thick and cured by ponding water and the other 6 in. (150 mm) thick and cured by wetting the surface followed by covering it with plastic sheeting. The initial concrete temperature was 90°F and the initial curing water temperature was about 35°F (2°C), producing a 55°F temperature difference between the concrete and curing water. The concrete mixture proportions comprised 564, 253, 1892, and 1214 lb/yd^3 (335, 150, 1122, and 720 kg/m^3) of Type I/II portland cement, water, coarse aggregate, and fine aggregate, respectively, plus 4 fl oz/cwt (260 mL/100 kg) of a mid-range water-reducing admixture.

Concrete was placed in the two forms, consolidated, struck-off, and floated. An immersion thermometer was inserted in the concrete at a corner of the slab to be cured with plastic sheeting and it was removed right after curing water was added. Final hand floating and then troweling were started when a footprint indention was about 1/4 in. (6 mm). As soon as water was added to a depth of 1 in. (25 mm) on the ponded specimen, an immersion thermometer was used to measure the temperature of the ponded water. Several gallons of curing water were slowly poured on the other slab at one edge, flooding the entire concrete surface for several minutes. Plastic sheeting was then placed on the slab and smoothed to eliminate most of the air bubbles. Boards were placed on the slab to hold down the plastic and shield the surface from direct sunlight to minimize mottling that would make it difficult to observe any cracks.

Temperature measurements showed that 1 minute after ponding, the ponded curing water temperature had risen from 35 to 50°F (2 to 10°C). Fifteen minutes after ponding, the water temperature was 21°F (12°C) lower than the concrete temperature.

The surfaces of both slabs were examined for cracking just before curing water was added, and they were observed for cracking each time the ponded water temperature was measured. No crazing or thermal cracking was noted, including in the area where all the curing water was added to the slab that was subsequently covered with plastic sheeting. After 1 week, water was drained from the ponded slab and as the surface dried, it was examined for cracks. The surface of the slab cured with plastic sheeting was wetted and also checked for cracks as it dried. No cracks were noted in either slab.

These simple tests showed that a 55°F temperature difference between the concrete and curing water did not induce cracks in concrete. The tests also showed that the concrete heated the curing water fairly quickly.

Measuring internal temperatures—North S.Tarr Concrete Consulting (NSCC)

While the MTSU tests indicated that cold curing water did not crack concrete test slabs, the tests provided temperature change data only on the ponded water. NSCC was contracted to obtain temperature profiles in the concrete after surfaces were flooded with cold curing water, using thermistors installed as in a previous research project studying the effect of cold reinforcing bars on concrete.[16]

A 2 x 3 ft x 5-1/2 in. deep (610 x 915 x 140 mm) form was built to hold concrete (Fig. 5). Using thin fishing line, thermistors were attached to taut strings installed at different depths relative to the top of the form (1/8, 1/4, 1/2, 1, and 2-1/2 in. [3.2, 6.4, 12.7, 25.4, and 63.5 mm]). Thermistors were centered vertically on the string and their wire leads were taped to the string to hold the sensors in place and to minimize damage to the wires during concrete placement. A jig with horizontal nail spacers was used to hold the string/thermistor sensors in place vertically while concrete was

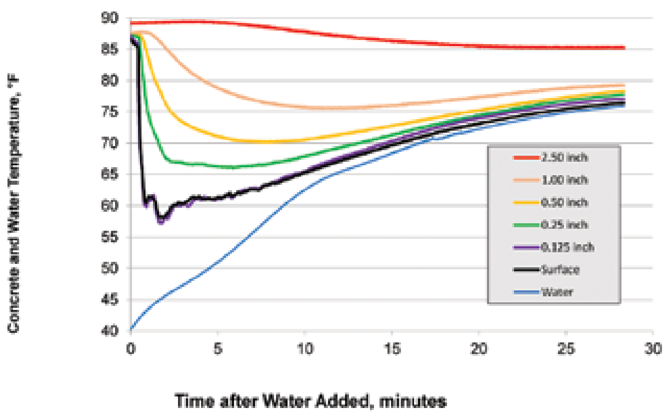


Fig. 6: Concrete and water temperatures versus time after curing water was poured on the concrete surface

Fig. 7: After 1-1/2 hours, the ponded curing water was removed, the slab surface was checked for cracks, and then 36°F curing water was reapplied to the concrete surface. No cracking was observed during or after drying of the surface

being placed. The vertical spacing jig was removed once concrete was placed around the thermistors. An additional thermistor was worked into the surface of the concrete during the finishing process to capture temperature readings just beneath the top surface.

A National Instruments NI USB-6218 multifunction data acquisition module with 16-bit precision was used to collect sensor data. Sensors were Measurement Specialities thermistors with factory-applied plastic caps and lead wires. Measured resistance values were converted to temperature using the manufacturer's tabulated resistance-temperature data. Temperatures were measured at 1/60-second intervals.

The concrete mixture proportions comprised 564, 282, 1750, and 1373 lb/yd^3 (335, 167, 1038, and 815 kg/m^3) of Type I/II portland cement, water, coarse aggregate, and fine aggregate, respectively, plus 3.5 fl oz/cwt (228 mL/100 kg) of a Type A water-reducing admixture. Concrete was placed, consolidated, struck-off, and floated. Hand floating, then troweling were started when the concrete had stiffened to about a 1/4 in. footprint indentation. A dam was built on top of the concrete form so that 1/2 in. of curing water could be added. The initial concrete temperature was 86°F (30°C) and the initial curing water temperature was about 40°F (4°C), representing a 46°F (26°C) temperature difference between the concrete and curing water.

Time-temperature results

Figure 6 shows the concrete and water temperatures measured after curing water was poured on the concrete surface. The 40°F curing water caused the temperature of the concrete surface and the top 1/8 in. of concrete to drop about 30°F, from 87 to 57°F (30.5 to 14°C). The concrete temperatures at 1/4, 1/2, and 1 in. depths also dropped. The curing water temperature rose quickly, from 40 to 50°F in 5 minutes, and it continued to rise. Within 10 minutes, the difference in curing water and concrete surface temperatures was only 3°F (2°C). Figure 6 also shows that within 30 minutes, the water and all internal concrete temperatures were within 10°F (6°C) of each other.

In the MTSU test, the curing water temperature rose more quickly than in the NSCC test. This may be due to the MTSU tests having been done at noon on a day when the sun was shining and the ambient temperature was over 90°F. Thus, the sun and air temperature helped the concrete heat the curing water. The NSCC test was done at night, with the curing water added about midnight, thus simulating a concrete night placement where the ambient temperatures were dropping and there was no sun. It took about 15 minutes in both MTSU and NSCC tests for the curing water temperature to be 20°F (11°C) lower than the internal concrete temperature near the middle of the slab.

After 1-1/2 hours, the ponded curing water was removed, the slab surface checked for cracks, and then 36°F (2°C) curing water was reapplied to the concrete surface. Similar temperature-time results were obtained with the second application of curing water. Again, after removal of this colder curing water at 72 hours after casting, no surface cracking was observed (Fig. 7).

It should be noted that this was the second time that a ponding test was performed by NSCC. The first time, the initial concrete temperature was 85°F (29°C) and the initial curing water was 35°F. The test was repeated because the software program collecting the temperature data didn't work. However, no concrete surface cracking was noted on this first test at 72 hours.

Analysis of Test Results

The initial concrete temperatures for MTSU and NSCC tests were 90 and 86°F, respectively. In both test programs, ice was used to obtain a curing water temperature of 40°F or less. Obviously, contractors don't use ice to chill the curing water on projects, so these test conditions represent the highest generally accepted concrete temperatures and the lowest possible curing water temperatures. In these extreme conditions, the NSCC test resulted in a maximum temperature differential of 30°F between the probe placed at the slab surface and the probe placed at a 2-1/2 in. depth in the slab. This difference was measured about 2 minutes after the slab was wetted. Yet, there was no cracking.

Conclusions

It is broadly recognized that current practice seldom includes heating curing water. Inductive reasoning leads us to conclude that normal temperature differences between curing water and concrete surfaces do not promote cracking, as there certainly must have been numerous projects that included cold curing water on hot concrete.

Neither the MTSU nor the NSCC test program resulted in cracking of concrete surfaces—even with severe and unrealistic temperature differentials of 55 and 50°F, respectively. The tests therefore confirm that an inelastic analysis using experimentally measured strain capacity provides a more appropriate model of concrete behavior than an elastic analysis using a strain capacity typically assumed for hardened concrete.

It is suggested that conservative guidance supports curing water and concrete temperature differences of at least 35°F. This is consistent with ACI 301-16,[17] Section 8.1.3, and ACI 207.1R-05,[18] Section 4.6, which indicate that concrete surface cracking should not occur if the internal concrete temperature difference is less than 35°F. This is also supported by ACI 207.4R-05,[19] Section 3.3.2, which indicates that cooling water at temperatures as low as 37°F and mixtures of water and antifreeze at temperatures at 33°F have been used successfully in embedded pipes to cool mass concrete. ACI 207.2R-07,[20] Section 4.6.2 (Example 5), includes a sample calculation showing how many days it will take to lower the temperature of mass concrete if the initial concrete temperature is 105°F and the circulating cooling water is at 38°F—a temperature difference of 67°F. This large difference provides additional evidence that a 35°F temperature difference between curing water and concrete is not going to cause cracking of a concrete surface.

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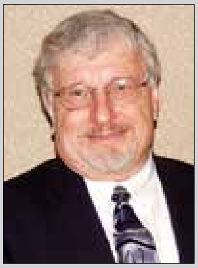

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Workability and Setting Time for Slipform Paving Concrete Mixtures

Evaluation of two test methods

by Peter C. Taylor and Xuhao Wang

Technical Session Organized by ACI Committees 231 and 325

ACI Committees 231, Properties of Concrete at Early Ages, and 325, Concrete Pavements, are jointly sponsoring a session at The ACI Concrete Convention and Exposition, October 23-27, 2016, in Philadelphia, PA. The session, "Early Age Concrete Properties Measurement for Concrete Pavement Construction Operations and Traffic Opening," is intended for practitioner engineers, specification writers, contractors, staff members with departments of transportation, professors, and students. Presentations will promote best practices for obtaining the early age concrete properties needed for good concrete pavement performance. Attendees can expect to learn how to base their assessments of concrete on reliable measurements instead of empirical evaluation or "guestimates."

Session organizers Wayne Wilson, LarfargeHolcim, and Jussara Tanesi, SES Group & Associates LLC, received many interesting and timely abstracts, and they arranged for some of the associated articles to be published in *Concrete International*. This is one of the two articles included in this month's *CI*.

A challenge to specifying and producing uniformly high-quality concrete pavements has been a lack of test methods that evaluate the properties of a mixture that impact longevity of the system. To meet that need, significant efforts have been ongoing at Iowa State University and other institutions. This article discusses two test methods being implemented as a result of these efforts—the vibration Kelly ball (VKelly) test and the ultrasonic pulse velocity (UPV) test.

The first test assesses the workability of a fresh, low-slump concrete mixture, in particular its response to vibration, which is the critical measure of workability in the context of slipform paving. The second test uses acoustical methods to predict when sawcutting should be conducted for a given mixture under given weather conditions, potentially saving millions of dollars in random cracking prevention and/or excess overtime for sawing crews waiting for the concrete to harden sufficiently.

This article discusses the principles behind each test, the research data collected to validate them, and results from field evaluations.

VKelly Test for Workability

As defined in ACI 238.1R-08, Section 2.2,[1] workability is: "that property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated, and finished to a homogenous condition." Traditionally, the slump test has been the fallback test method for evaluation of workability, especially when balanced by visual assessments by experienced operators.[2] However, the slump test does not provide a complete description of rheology or thixotropy of a mixture.

Before the adoption of supplementary cementitious materials and water-reducing admixtures, the slump test provided a means of assessing potential performance of a hardened mixture, because it is so strongly influenced by water content. However, the increasing complexity of mixtures has meant that this correlation is no longer valid.

For slipformed concrete, the ideal workability is a challenge to measure and achieve. On the one hand, it's desirable that the concrete flows readily as it is moving through the paving machine under vibration. On the other hand, the slab should exhibit little or no edge-slump as the machine moves away. Concrete that fails to exhibit either of these behaviors may not have the correct dimensions or be well consolidated throughout its section.

Concrete may be considered a Bingham fluid and can thus be characterized by two parameters—yield stress and plastic viscosity. Yield stress is a measure of how much energy is required to initiate movement, while plastic viscosity is a measure of how much energy is required to accelerate the movement. These properties are independent for a given material and both need to be determined to fully characterize a mixture. The slump test may be considered to measure only the yield stress. It has been reported that two different mixtures with the same slump will respond very differently under vibration, primarily due to variations in the binder type and gradation of the fine aggregate.[3]

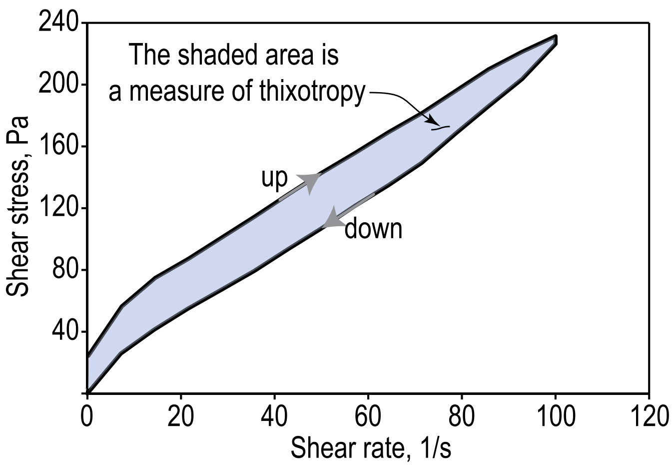

Fig. 1: Illustration of how thixotropy is evaluated (after Reference 4) (Note: 1 Pa = 0.000145 psi)

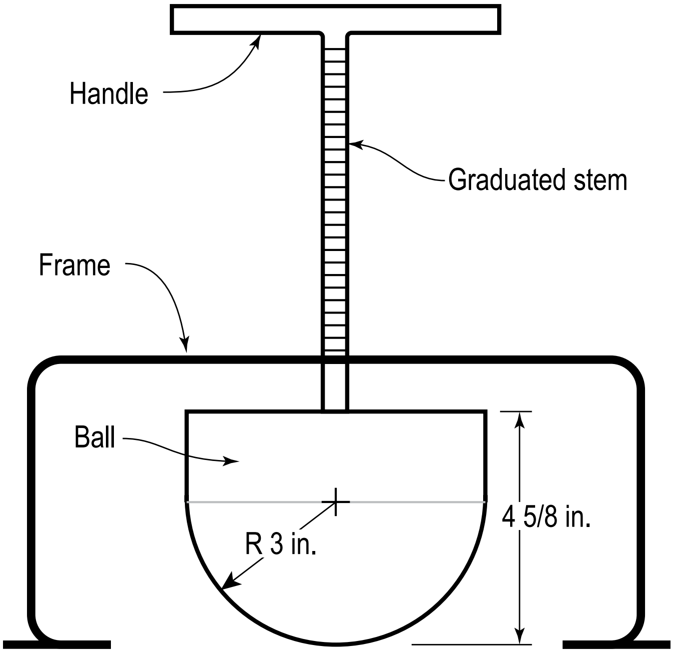

Fig. 2: Kelly ball apparatus[7] (Note: 1 in. = 25 mm)

Thixotropy is a time-dependent behavior in which viscosity of a material decreases with time under shearing but recovers to its original value when the shearing ceases. This rate-dependent shear thinning parameter is typically exhibited as hysteresis in a shear stress versus shear rate plot (Fig. 1). Thixotropy can be assessed by determining the area between the up and down curves as shear rate is increased and then decreased. A high value of thixotropy is desirable in slipformed concrete because when vibration ceases, the mixture should no longer need a form to retain its shape.

Rheology is the study of fluids by determining yield stress, plastic viscosity, and thixotropy. Typically, a blade or cylinder is rotated in a mixture at varying rates to determine these properties. However, because slipform concrete conventionally has a very low slump of about 1 in. (25 mm), it is not considered a liquid and cannot be handled with commercially available rheometers. The fundamental need for the paving industry then is a test that reports two parameters, most notably the response of a mixture to vibration.

Procedure

Many workability test devices have been specifically designed for evaluation of the response of low-slump concrete subjected to vibration. Evaluations of some of these, including the Vebe consistometer, flow table, vibrating slope apparatus, angels flow box, and Wigmore consistometer, have been summarized elsewhere.[3] The common drawbacks of these apparatus and methods include:

- The size of the test device is generally unsuitable for field measurement;
- The test is not cost-efficient; and
- The method is not effective in distinguishing changes in mixtures.

The aim of the work reported herein was to develop a test method that identifies and reports the workability parameters that are important when preparing a mixture for use in slipform paving. This proposed method would also report both static and dynamic characteristics while simulating the effect of vibration from paving and has a potential to overcome the drawbacks reported in other workability test methods. The approach was to modify an existing test apparatus, the Kelly ball, by adding vibration energy as discussed below.

The Kelly ball was developed in the 1950s in the United States and formerly standardized in ASTM C360-92, "Test Method for Ball Penetration in Freshly Mixed Hydraulic Cement Concrete" (withdrawn in 1999).[5,6] The Kelly ball apparatus weighs a total of 30 lb (13.6 kg) and consists of a 6 in. (152 mm) steel cylinder with a hemispherically shaped bottom, as shown in Fig. 2. The shaft is graduated in 1/4 in. (6 mm) increments and slides through a frame to measure the depth of penetration. The ball is placed on a leveled concrete surface and the depth of penetration is recorded after the ball is released. The slump measured by the slump-cone test is typically 1.1 to 2.0 times the Kelly ball test reading for normalweight concrete.[7]

The VKelly apparatus (as shown in Fig. 3) is based on the Kelly ball apparatus with a vibrator attached to the ball. After several trials, a 13/16 in. square vibrator head, 13 in. long (20 mm square, 330 mm long) was adopted. The vibrator head is coupled with a motor that can provide 72 ft·lb (100 J) energy at a constant frequency of 8000 vibrations per minute (vpm). This frequency was selected as being representative of the frequency of vibrators used in slipform pavers. The top part of the steel ball was partially hollowed out (as shown in Fig. 3) to compensate for the added weight of the vibrator. The VKelly ball therefore retains the same dimensions, surface area, and apparatus weight (30 lb) as a static Kelly ball.

The VKelly test procedure includes the following steps:

- Discharge fresh concrete into a wheelbarrow or other container to a depth of at least 6 in. (150 mm) for 1 in. aggregate or smaller, and 8 in. (200 mm) for larger aggregate;
- Create a leveled area of about 1.5 ft^2 (0.3 m^2) by gently tamping the concrete. Avoid overworking the surface, as this would cause excessive buildup of mortar at the surface and thus result in erroneously high penetration readings;
- Gently lower the ball until it touches the surface of the concrete. Make sure the shaft is vertical (normal to the surface of the concrete) and free to slide through the yoke. Take an initial reading to the nearest 1/4 in., and then gradually allow the ball to sink into the concrete. When the ball comes to rest, record the second reading to the nearest 1/4 in. Report the difference between the two readings multiplied by a factor of 2.0 as the Kelly ball-measured slump;
- Turn on the vibrator (preset to 8000 vpm) and simultaneously start the timer. Record the readings on the graduated shaft at 6 second intervals up to 36 seconds. A video recorder can be used to simplify recording the VKelly penetration depths during vibration;
- In the laboratory: remove the VKelly apparatus and remix the concrete sample for about 30 seconds. Then, repeat the measurement process by creating a leveled area, measuring the Kelly ball-measured slump, and recording the VKelly penetration depths during vibration. Remove the VKelly apparatus, remix, and conduct Kelly ball and VKelly measurements a third time. For any given time in a VKelly measurement cycle, the penetration depth should be within 1/2 in. (13 mm) of the average of the readings from the three measurement cycles;
- In the field: repeat the procedure using fresh concrete from the same batch;
- Plot the averaged increment of penetration readings, in in. (or mm), on the vertical axis against the square root of vibration time, in $\sqrt{seconds}$ ($\sqrt{s}$), on the horizontal axis (Fig. 4); and

Fig. 3: VKelly apparatus

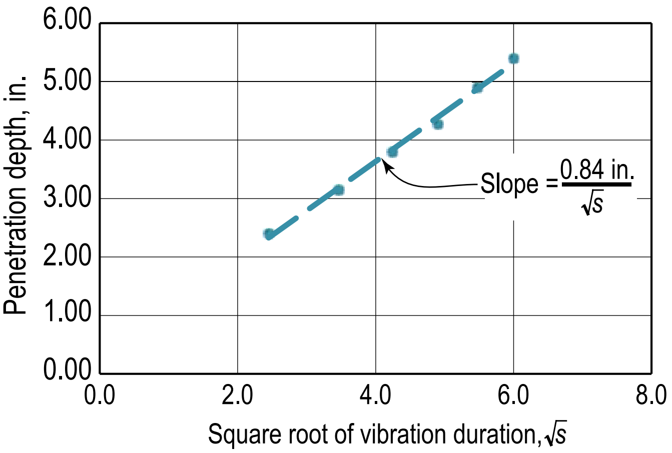

Fig. 4: Sample plot of VKelly test results. In this example, V_{index} = 0.84 in. /$\sqrt{s}$ (Note: 1 in. = 25 mm)

- Determine the slope of the best fit line from $\sqrt{6s}$ to $\sqrt{36s}$ by conducting a linear regression analysis of the data. Report the slope, V_{index}, in in./$\sqrt{s}$ (or mm/$\sqrt{s}$).

Validation

A laboratory program was conducted to confirm that the method would identify variations between mixtures. A control mixture was developed, and multiple test mixtures were produced by varying the amount of a single ingredient while adjusting other ingredients to maintain a consistent yield.

Slump and VKelly tests were conducted using more than one operator. Each mixture was tested three times and the resulting data were averaged.

The control was an ordinary portland cement concrete mixture with 564 lb/yd³ (335 kg/m³) cementitious materials, water-cementitious material ratio (*w/cm*) of 0.45, fine aggregate-to-coarse aggregate ratio of 45/55, and target air content of 5%. Aggregates were local to Ames, IA, and comprised river sand and 1 in. crushed limestone.

The variables and target values were:

- Sand—increments of 100 lb/yd³ (60 kg/m³) (+1, +2, +4, −1, −2, and −4);
- Air—increments of 1% (+2 and −2);
- Class C fly ash—increments of 10% by weight of the cement (+1, +2, and +3);
- Water—increments of 10 lb/yd³ (5 kg/m³) (+1 and +2); and
- Replication—plain mixture rebatch, remix, and remix at different elapsed time.

The test results are listed in Table 1.

Generally, increasing the fine aggregate content up to 400 lb/yd³ (240 kg/m³) seems to increase the VKelly index, while decreasing the fine aggregate content gives a lower index value. As expected, increasing the Class C fly ash dosage and increasing the water content result in slight increases in VKelly indexes. VKelly indexes also tend to decrease with decreasing air content.

Table 1:
Laboratory VKelly test results

Mixture ID*	Slump, in.	Slump measured by VKelly test, in.	Air content, %	Unit weight, lb/yd³	VKelly index (average)	Multi-operator VKelly index statistics			
						Operator 1	Operator 2	Δ	%, Δ
Sand −4	0.75	0.80	4.8	152.4	0.47	0.45	0.49	−0.04	8.31
Sand −2	0.75	1.00	5.3	149.0	0.46	0.46	0.47	−0.01	2.15
Sand −1	0.75	1.00	4.5	151.4	0.46	0.45	0.48	−0.03	6.45
Sand +1	1.00	1.00	5.5	146.4	0.57	0.58	0.56	0.02	2.63
Sand +2	1.00	1.75	5.4	149.6	0.50	0.50	0.49	0.01	2.02
Sand +4	1.10	1.20	4.5	148.9	0.73	0.72	0.74	−0.02	2.74
Air +2	1.50	2.00	7.0	147.4	0.66	0.66	0.66	0.00	0.30
Air −2	1.00	1.00	5.8	147.4	0.64	0.63	0.65	−0.02	3.13
C Ash +1	1.00	1.50	5.0	148.0	0.63	0.64	0.62	0.02	3.17
C Ash +2	1.00	1.10	5.0	148.3	0.68	0.68	0.68	0.01	0.74
C Ash +3	1.25	1.50	5.5	147.4	0.72	0.71	0.73	−0.02	2.09
Plain	1.00	1.25	4.5	147.6	0.58	0.58	0.59	−0.01	2.06
Plain (2)	1.00	1.10	4.7	147.8	0.61	0.61	0.61	−0.01	0.99
Plain (2) + 1 Gal	—	1.25	—	—	0.70	0.72	0.69	0.03	4.40
Plain (2) + 2 Gal	—	1.60	—	—	0.74	0.74	0.73	0.01	1.36
Plain (3)	1.25	1.10	5.2	148.6	0.62	0.61	0.63	−0.02	3.38
Plain (4)	1.25	0.90	5.5	148.0	0.68	0.67	0.68	−0.01	1.48
Plain (3) at 15 min.	—	1.35	—	—	0.61	0.60	0.62	−0.02	3.11
Plain (3) at 30 min.	—	1.05	—	—	0.61	0.61	0.62	−0.01	1.80
Plain (3) at 45 min.	—	0.90	—	—	0.55	0.55	0.54	0.01	1.83
Plain (4R)	—	1.00	—	—	0.67	0.66	0.69	−0.03	3.86
Plain (4R) at 15 min.	—	1.05	—	—	0.67	0.65	0.69	−0.04	5.37

*(2), (3), and (4) denote the second, third, and fourth repeats; (R) denotes remix

Note: 1 in. = 25 mm; 1 lb/yd³ = 0.6 kg/m³

Table 1 includes statistical data for VKelly indexes measured by two operators. The indexes varied from 0.00 to 8.31% for the same test, indicating a low multi-operator error. The repeatability of VKelly test performed by a single operator was also verified. The plain mixture was repeated (batched) four times and the standard deviation of the index obtained from these four batches was 0.037 in./$\sqrt{s}$ (0.94 mm/$\sqrt{s}$).

To check the influence of elapsed time and remixing on the VKelly index, the index was measured on one of the four plain mixtures at 15 minute intervals up to 45 minutes elapsed time after mixing. The index slightly declined as elapsed time increased, as shown in Table 1. Also, the standard deviation obtained for all the plain mixtures is 0.041 in./$\sqrt{s}$ (1.042 mm/$\sqrt{s}$). It can be observed that the mixtures with similar slump may have various VKelly indexes, indicating that the mixtures respond differently to vibration.

Limits

Data were collected as part of another program[8] to assess the limits of what may be considered as "good" or "bad" VKelly indexes for slipform paving. Mixtures were prepared that ranged from deliberately dry to deliberately wet so that the VKelly test could be performed over a wide range of workability.

For these tests, two types of coarse aggregate were used, limestone and crushed gravel (LS and G) with 1 in. nominal maximum aggregate size. All mixtures were prepared with natural river sand. Two aggregate gradation systems were used for each aggregate type: one with a fixed 50/50 of coarse to fine aggregate content, and the other that was sieved to fit within a Tarantula curve, as shown in Fig. 5.[9] A constant Class C fly ash replacement level, 20% by the weight of cement, was used, and the *w/cm* was 0.42. Either two or three cementitious material contents were used with each aggregate system.

Figure 6 presents the relationship between cementitious material content and VKelly index. As expected, VKelly index values increases with increased cementitious material content. Generally, the aggregate system that fell within the Tarantula curve gave a higher VKelly index, indicating a better response to vibration. Interestingly, the crushed limestone aggregates appeared to respond better to vibration than the gravel, particularly for the poorly graded system.

Based on observations of the mixtures, a VKelly index range of 0.6 to 1.2 in./$\sqrt{s}$ (15 to 30 mm/$\sqrt{s}$) appeared to indicate mixtures suitable for paving.

Field tests

The VKelly test was also conducted at a number of slipform paving construction sites, including interstate and state highways and rural and urban roads.[3] Pavement types included reconstruction, new pavement, and bonded and unbonded overlays. The slumps measured by VKelly apparatus were in the range of 1.0 to 2.6 in. (25 to 66 mm) and were consistent with the values measured by the slump

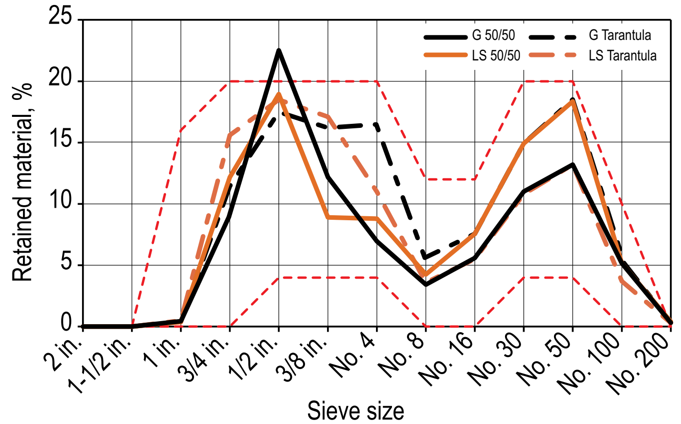

Fig. 5: Four combined aggregate gradations plotted on a Tarantula curve (after Reference 9) (Note: 1 in. = 25 mm)

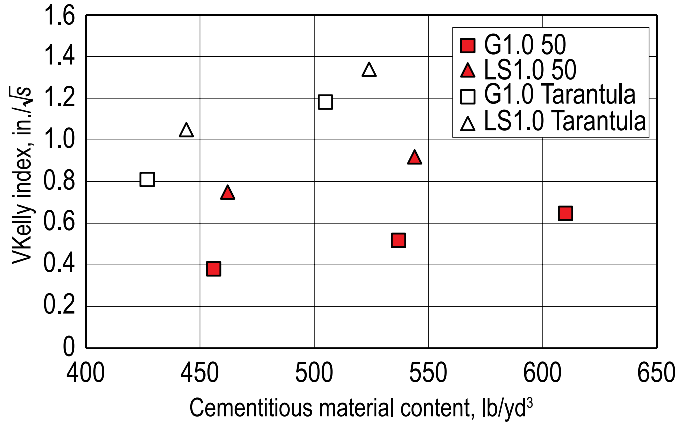

Fig. 6: VKelly index versus binder content[3] (Note: 1 in. = 25 mm; 1 lb/yd^3 = 0.6 kg/m^3)

cone test (ASTM C143/C143M[10]). VKelly index values of above 1.3 in./$\sqrt{s}$ (33 mm/$\sqrt{s}$) were associated with edge slump at a site with integral edge drains. This indicates an upper limit of VKelly index of about 1.2 in./$\sqrt{s}$ is appropriate. A lower limit has not yet been determined in the field.

UPV for Sawcutting

The primary purpose of sawing joints in slipform concrete pavement is to control random cracking. A weakened plane can be introduced to ensure cracking occurs in a controlled manner at specific locations. Sawcutting is considered as the most practical way to induce joints for slipform paving operations.

At present, however, there is little solid guidance regarding the ideal time the sawcut should be installed in slabs. ACI 224.3R-95, Section 2.8.3,[11] recommends that "joints should be sawed as soon as practical" wherein the "concrete should have hardened enough not to ravel during cutting." Indiana Department of Transportation specification, Section 503.03,[12] specifies a 2- to 12-hour sawing window for transverse joints and "sufficiently hardened" for longitudinal joints. Cutting too early increases the risk of raveling and spalling, but cutting too late increases the risk of random cracking. There are, therefore, financial benefits to optimizing sawcutting times. Fewer slabs will need to be replaced or patched due to raveling, spalling, or random cracking, and overtime costs can be reduced because sawing crews can be called in when slabs are ready.

Approaches to determining the "right" time to conduct sawing on a fresh-paved concrete slab tend to be subjective. The most commonly used method for sawcutting crews is to scratch the slab surface with a penknife or to stand on the slab to observe footprint depth. An alternative is to try a cut and observe the degree of raveling. However, a very clean cut may indicate that it is already too late and that the risk of random cracks running in front of the blade is high. Other researchers have established several approaches to predict the sawing window, including calorimetry, finite element modeling, HIPERPAV software, maturity meter, penetration resistance, and UPV methods.[13-18]

Others have reported using thermography for this application, but this approach is constrained because it does not take into account the weather at the time of placing.[19,20] In the method described in the following sections, a cylindrical concrete sample is placed in UPV test equipment near the pavement. The sample and the pavement slab are therefore exposed to the same environment.

The UPV method is based on the fact that sound travels slower in a fluid than in a solid.[13] The velocity of sound can be determined using a device that tracks the time for a signal to travel through a sample with a known depth. The method used in the study reported here measures the velocity of compression waves (P-waves) traveling through the material.[21] According to Biot's theory,[22,23] the velocity of sound in a continuous medium is a function of elastic modulus, density, and Poisson's ratio.

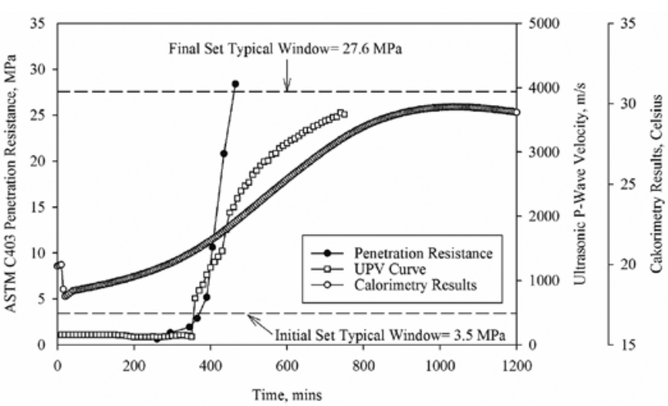

Fig. 7: Plots from different measurement techniques for a lab mixture[13] (Note: 1 MPa = 145 psi; 1 m = 3.3 ft; °F = 1.8 × °C + 32)

Fig. 8: UPV test setup with sample and transducers in a wooden frame for stability

Previously reported work showed a clear relationship between initial setting time determined by penetration resistance and that determined using speed of sound through the same sample as recorded by a UPV device (Fig. 7).[13] When the mixture is fluid, the speed of sound is constant, but as solids start to percolate across the sample, then the speed of sound accelerates. The study reported herein included measurements to determine if a correlation exists between setting times measured in the field by the UPV method and sawing times on the same slabs.

Field work

A commercial UPV device was used to track pulse velocity of field concrete samples (Fig. 8) on more than 24 pavement construction sites around the Midwest from spring through fall during a 3-year period (from 2013 to 2015). Sites included city and county streets and DOT mainline pavements. Mixture proportions and ingredients varied by location and were recorded in Wang et al.[24]

The test system is composed of an integrated waveform display, two longitudinal wave transducers with a frequency of 54 kHz, and an acrylic rod for calibration (the velocity of sound through acrylic served as a calibration standard). The top transducer was set on an acrylic sheet sized to fit inside the cylindrical mold. The bottom transducer was set in contact with the bottom of the mold. A gel couplant was applied between each transducer and the two contact surfaces (the acrylic sheet and the mold bottom) to reduce attenuation of the sound waves at the interfaces.

At each site, a concrete sample was taken from in front of the paver. A 4 x 8 in. (100 x 200 mm) cylinder mold was filled and consolidated by rodding in accordance with ASTM C31/C31M.[25] The specimen was then placed in a wooden frame next to the pavement slab so that it was exposed to the same environmental conditions as the slab. The test was started immediately after the upper sensor was installed. Initial setting was indicated when the speed of sound accelerated markedly. The time when the crew sawcut the same section of pavement was also recorded (crews were given no instructions regarding when they should cut). Using the time of mixing as the start, elapsed times to initial setting and to sawing were recorded and plotted (Fig. 9). The data point indicated "non-typical conventional saw" in Fig. 9(b) was obtained when a sawcutting crew used a span saw machine, which is heavier than typical, conventional saw machines. Because of the extra weight, the crew made a late cut.

As seen in Fig. 9, the correlation between UPV initial set and sawing time is remarkably close considering the variables that were not controlled in this work, including mixture proportions and ingredients, sawcutting crew experience and methods, ambient temperature, and pavement thickness. The mixtures used to establish the relationship consisted of limestone, granite, and quartzite as coarse aggregate, so the aggregate types appear to have no effect on sawing times for the mixtures tested in this study. Two general prediction equations were established elsewhere to provide a reference to contractors rather than indicate an exact sawing time.[24]

It should be noted that no random cracking was observed at any of the sites monitored in this work. There was, however, a relationship between ambient temperature and sawing time, with cooler conditions delaying sawing (Fig. 10). One of the advantages of applying this approach to track concrete setting behavior is that the test sample was measured under the same ambient conditions as the paving concrete; therefore, field concrete was simulated. While the temperature in the slab could be different from that in the sample, the differences should be smaller than the ones that would be seen between pavement and samples in a semi-adiabatic calorimeter.

Summary

Two test methods have been presented that have the potential to help the concrete paving industry place better-quality pavements at lower cost.

The VKelly test appears to provide useful information regarding the response of a mixture to vibration. It is expected that this device will be useful primarily to the contractor during the mixture design phase. Adjustments to mixture proportions (such as fine aggregate gradation) can be monitored for their effects on workability, potentially leading to development of mixtures that will provide balance between the need to be easily workable under vibration, yet be immune to edge slump.

The proposed UPV approach looks promising for predicting sawcutting times in the field. A pavement mixture can be calibrated during the first day of paving, and ongoing UPV measurements can be used to indicate sawing times for the remainder of the project. The technology thus has the potential of saving millions in rejected pavements and unnecessary overtime costs.

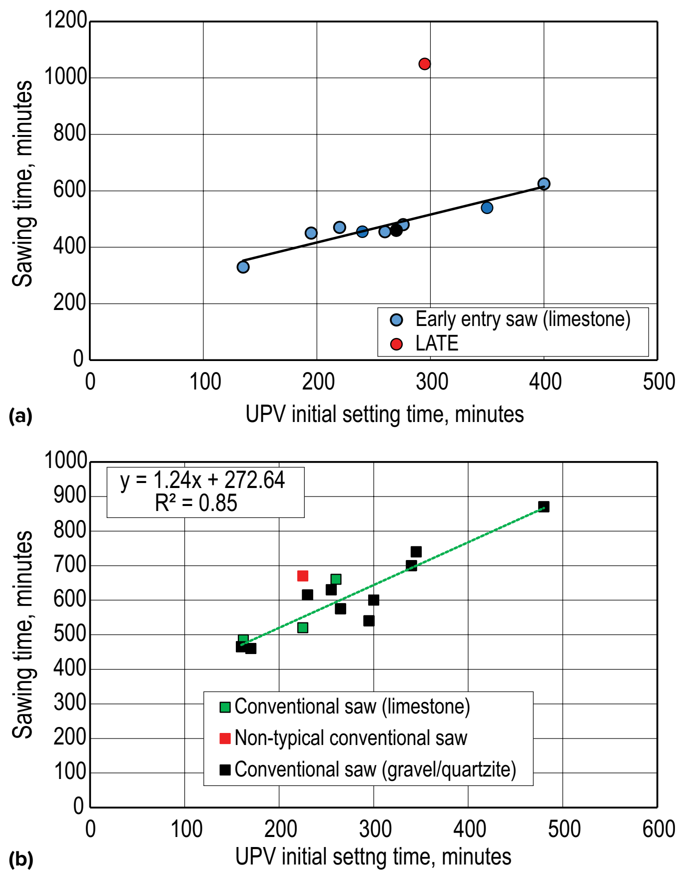

Fig. 9: Initial setting time from UPV measurements[14,15] versus sawing time for (a) early entry saw; and (b) conventional saw

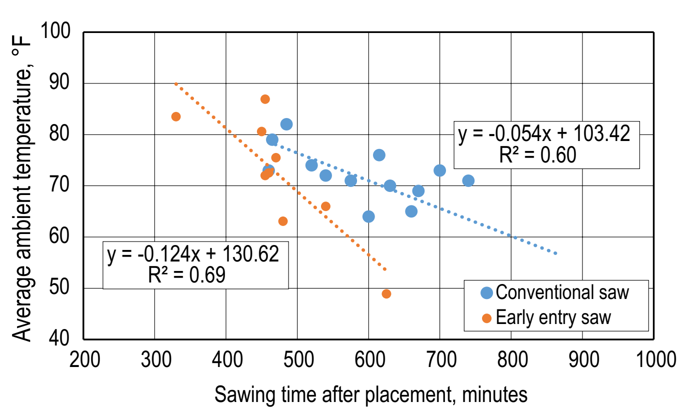

Fig. 10: Relationships between average ambient temperature and sawing time, as a function of saw type[15] (Note: °C = (°F − 32)/1.8)

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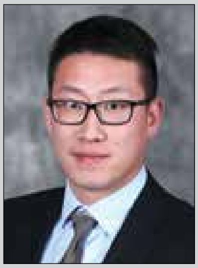

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Increasing the Strength of Concretes Made with Blended Cements

Physical approach to increasing packing density of binder particles

by Pierre-Claude Aïtcin, William Wilson, and Sidney Mindess

To lower the carbon footprint of concrete structures, blended cements are increasingly replacing ordinary portland cements in North America. The environmental gains are significant, as the substitution of each kilogram of portland cement clinker results in a decrease of about 0.8 kg (1.8 lb) of CO_2 emissions associated with cement production. Blended cements (binders) contain fillers or supplementary cementitious materials (SCMs), which are less reactive than the portland cement, change the hydration process, and thus reduce the early compressive strengths. At least two approaches may be taken to overcome this strength reduction:

- Increase the C_3S and C_3A contents of the clinker (the two most reactive phases of portland cement) and grind the blended cement more finely. Although this increases the reactivity in the short term, it does not improve the long-term compressive strength because the portland cement clinker has been "diluted" in the blended cement. Moreover, this approach is not an eco-friendly solution because increasing the C_3S content of the clinker requires an increased limestone content of the raw meal, leading to an increased amount of CO_2 emitted during clinker production. Additionally, grinding the blended cement more finely increases the consumption of electric energy. It is also more difficult to maintain a high slump value in the fresh concrete for 1-1/2 hours when using finer cements with increased C_3A and C_3S contents. In terms of durability, this approach results in increased contents of sulfate-bearing products (for example, ettringite) in the hydrated cement paste, which thus become more susceptible to sulfate attack or delayed ettringite formation; and
- Increase the packing density of the binder particles in the cement paste by using a high-range water-reducing admixture to lower the water-binder ratio (w/b), without changing the chemistry of the clinker. This approach is purely physical and will be emphasized in this article, using a simplified geometric model to visually illustrate its benefits.

A Simple Quantitative 3-D Model

Several more or less sophisticated mathematical models of cement hydration have been proposed in the literature.[1-3] Bentz and Aïtcin[4] used one of these models to demonstrate that the water-cement ratio (w/c) is directly related to the average distance between cement particles in a cement paste just before the beginning of hydration—the lower the w/c, the closer the cement particles are to one another and the stronger the concrete. In this article, a very simple, quantitative, three-dimensional (3-D) geometrical model is used to illustrate how a cement paste made with blended cement may be as strong as, or even stronger than, a cement paste made with a "pure" portland cement.

Portland cement paste

To model the cement paste, a network of spherical cement particles of radius a corresponding to a simple cubic arrangement is assumed, with a distance of $2.5a$ between the centers of the particles, as shown in Fig. 1(a). The system can be represented by a unit cell that contains 1/8 of a cement particle located at each corner of the cube for a total of one cement particle per unit cell, as shown in Fig. 1(b). The minimum distance between two cement particles is $0.5a$ along the sides of the cube.

The mass w/c of this unit cell is calculated assuming a specific gravity of 3.14 for portland cement and making the simplifying assumption that 3.14π is equal to 10 (instead of 9.86). The unit cell contains one particle of cement having a volume of $\frac{4}{3}\pi a^3$ and a mass of $3.14\times\frac{4}{3}\times\pi a^3=\frac{40}{3}a^3=13.33a^3$.

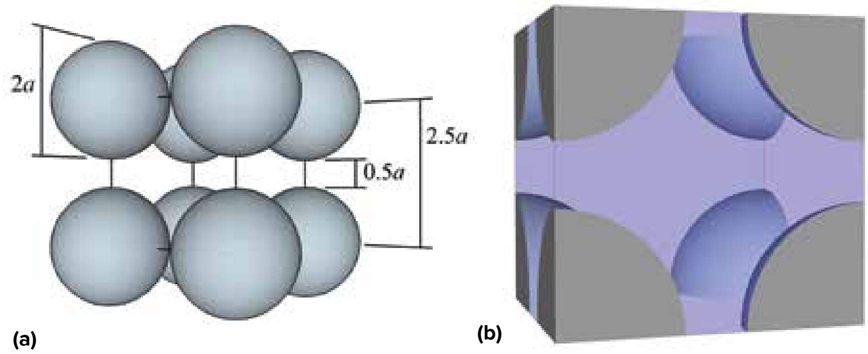

Fig. 1: A cubic system of cement particles: (a) network of spherical cement particles of radius *a*; and (b) a unit cell with 1/8 of cement particle in each corner

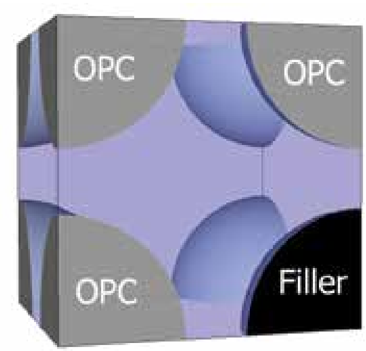

Fig. 3: Unit cell of blended cement containing 12.5% of filler

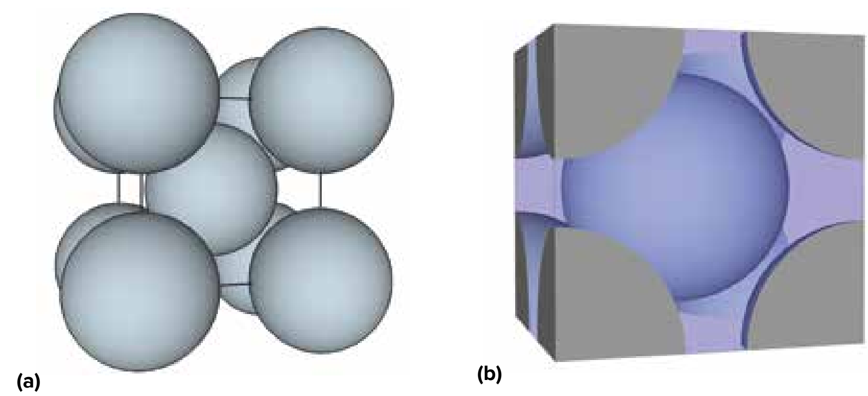

Fig. 2: A body-centered cubic arrangement of cement particles

The volume of water in the unit cell is equal to the volume of the unit cell minus the volume of the cement particle: $\left(\frac{5}{2}a\right)^3 - \frac{4}{3}\pi a^3 = 11.45a^3$. Therefore, the mass *w/c* of this system of cement particles is equal to $\frac{11.45a^3}{13.33a^3} = 0.87$.

This *w/c* is characteristic of a low-strength concrete having a compressive strength of less than 20 MPa (2900 psi). Because the minimum distance between two cement particles is 0.5*a* along the sides of the unit cell, this means that hydration products have to grow over a minimum distance of 0.25*a* before intermixing with the hydration products growing from adjacent cement particles.

Now, let us introduce a cement particle having the same radius *a* into the center of the previous cube, as shown in Fig. 2. This type of an arrangement is called a body-centered cubic system.

The unit cell now contains two cement particles. The mass of cement in this new unit cell has doubled; it is now equal to $26.6a^3$. The volume of water has consequently decreased to $\left(\frac{5}{2}a\right)^3 - 2\times\frac{4}{3}\pi a^3 = 7.27a^3$. In this system, the length of the diagonal is 2.5*a* and the shortest distance between two cement particles is 0.165*a* along this diagonal. Therefore, when the cement particles start to hydrate, the hydration products will have to grow only half this distance (that is, 0.083*a*) to begin intermixing with the hydration products growing from adjacent cement particles. This arrangement of cement particles leads to both high early strengths and high long-term strengths. The *w/c* of this new unit cell is 0.27, which is the *w/c* of a high-performance concrete having a compressive strength of about 100 MPa (14,500 psi). In other words, decreasing the minimum distance between two cement particles from 0.5*a* and 0.165*a* resulted in an increase by a factor of 5 of the compressive strength. This is in agreement with the results obtained using the more sophisticated model adopted by Bentz and Aïtcin.[4]

A good example of this effect of *w/b* on strength is the construction of a pedestrian bridge in Sherbrooke.[5] Using a relatively coarse portland cement with a Blaine specific surface area of 350 m^2/kg, a C_3A content less than 3.5%, and a C_3S content of 50%, Aïtcin et al.[5] were able to produce an ultra-high-strength concrete having a 24-hour compressive strength of 55 MPa (8000 psi), by reducing the *w/b* down to 0.20.

Blended cement paste

Now, let us replace a cement particle situated in a corner of our initial simple cubic unit cell by a *nonreactive* filler particle, as shown in Fig. 3. The *volumetric* substitution of the portland cement is 1/8, or 12.5%. The corresponding blended cement paste can be characterized by both ratios—its *w/b* and *w/c*.

The volumetric *w/b* of this blended cement is equal to the volumetric *w/c* of the previous system. The mass ratios now become *w/b* = 0.92 and *w/c* = 0.98 (instead of *w/c* = 0.87 for the system containing only portland cement). That is, the portland cement has been diluted. When this system starts to hydrate, the hydration products of a cement particle now have to grow a minimum distance of 0.5*a* to reach the inert filler

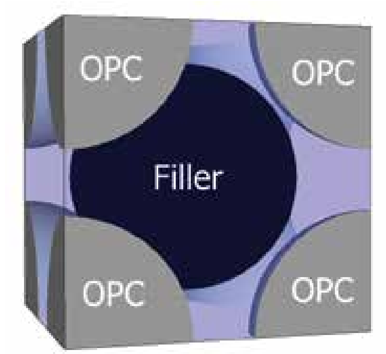

Fig. 4: Unit cell of blended cement containing 50% of filler

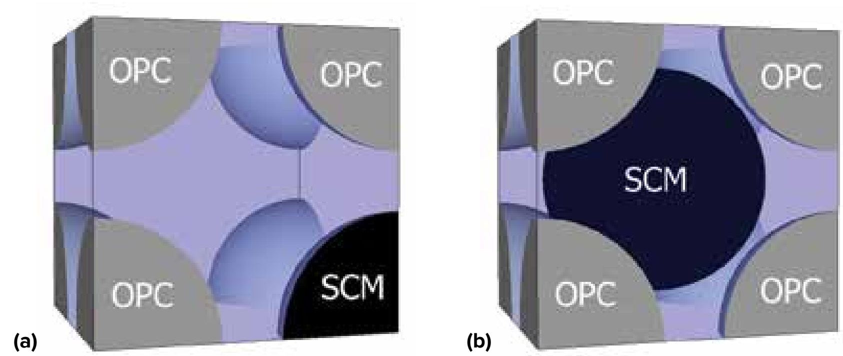

Fig. 5: Unit cells of blended cement containing 12.5% and 50% of SCM

particle. This is twice the distance between two cement particles in the initial simple cubic system because reactants will not be dissolved from the surface of the inert filler particle. It will thus take much longer to reach a given early strength, and the final strength of the system will be decreased.

Now, instead of substituting a filler particle at a corner of the simple cubic system, let us place a filler particle at the center of the unit cell whose corners are still occupied by cement particles, as shown in Fig. 4.

The volumetric substitution of cement particles in this blended cement is 50%. The volumetric *w/b* of this system is equal to the volumetric *w/c* of our second system (Fig. 2) containing a cement particle at the center of the initial cell. If the inert filler has a specific gravity of 2.72, the *w/b* of this system is equal to 0.30 instead of 0.27 for the portland cement-only system, because the specific gravity of the filler is lower than that of portland cement. When the cement particles begin to hydrate, the hydration products that develop along the diagonal have to grow over a distance equal to $0.165a$ to reach and encapsulate the central inert filler particle. When this nonreactive particle has been completely encapsulated by the hydration products growing from the eight adjacent cement particles, it can be considered to act as a hard inclusion that participates in the transmission of the stresses and thereby contributes to both the short- and long-term strengths of the blended cement paste.

In addition, it must be noted that not all of the fillers blended with portland cement can be considered inert. For instance, limestone fillers can also react slowly with C_3A to form carboaluminates that have binding properties.[6,7] Moreover, the favorable surface structure of limestone filler particles can allow them to act as nucleation sites for hydration products, which explains the accelerating effect of fine limestone additions.[8]

Now, instead of adding inert filler particles in the unit cell, let us insert SCM particles, such as fly ash (Fig. 5). In the short term, before there is significant pozzolanic reaction between the fly ash particles and the portlandite liberated by the hydration of the silicate phase, this system will behave like the previous ones containing inert filler particles.

However, when the fly ash does begin to react with the portlandite, the resulting solid matrix will be stronger than the comparable matrix containing filler particles. This matrix can become as strong as, or even stronger than, a matrix made up entirely of cement particles,[9] because portlandite crystals (containing many weak cleavage planes and representing up to 30% of the hydrated cement paste) are replaced by secondary C-S-H. Thus, the portlandite crystals that can be considered as weak inclusions in a pure portland cement paste are transformed by the pozzolanic reaction into additional C-S-H "glue."

Therefore, in terms of compressive strength, it is believed that the *w/b* of a blended cement paste is a much more critical parameter than the rate of substitution of the portland cement. Malhotra and Mehta[10] have experimented with substitution rates of portland cement above 50% in what they have called "high-performance, high-volume fly ash concrete," which is now increasingly used to lower the carbon footprint of concrete structures.[11,12]

However, it must be taken into consideration that blending portland cement with less reactive fine particles may delay the setting time by a few hours (this could be beneficial in hot weather concreting), or require the addition of accelerators in cold weather concreting.[10] Moreover, it is well known that the *w/c* may drastically change the conditions of cement hydration. When the *w/c* is high, hydration occurs initially as a dissolution/precipitation process, producing what is termed an external product. When the *w/c* is low, hydration occurs instead as a topochemical reaction leading to very dense hydration products having a vitreous character. Finally, it must be taken into account that the industrial fine powders blended with portland cement may contain some impurities (for example, carbon contained in fly ash) that can also alter the normal process of cement hydration, or the behavior of the admixtures that are used.

Conclusions

There are at least two different ways to increase the early compressive strength of blended cements. The chemical approach consists of increasing the fineness of the cement and the content of C_3S and C_3A in the clinker. This approach solves the short-term strength problem, but it does not improve the long-term strength of blended cements; it may also lead to less durable concretes. The physical approach, as illustrated herein using a very simple geometrical model, provides an increase of both the short-term and long-term strengths of cement pastes made with blended cement. However, when lowering the *w/b* of concretes made with blended cement, good water curing is of the utmost importance to mitigate its inherent autogenous shrinkage—it is the price to pay for decreasing the carbon footprint of concrete structures.

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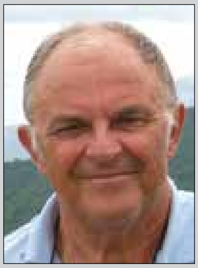

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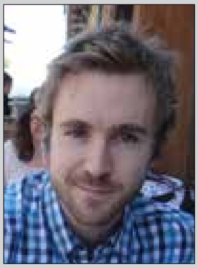

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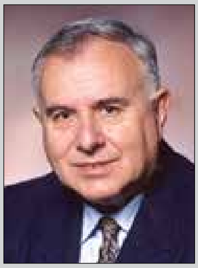

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What Do We Mean by "Setting?"

Rigorous to ambiguous interpretations

by Chang Hoon Lee and Kenneth C. Hover

Technical Session Organized by ACI Committees 231 and 325

ACI Committees 231, Properties of Concrete at Early Ages, and 325, Concrete Pavements, are jointly sponsoring a session at The ACI Concrete Convention and Exposition, October 23-27, 2016, in Philadelphia, PA. The session, "Early-Age Concrete Properties Measurement for Concrete Pavement Construction Operations and Traffic Opening," is intended for practitioner engineers and specification writers, contractors, staff members with departments of transportation, professors, and students. Presentations will promote best practices for obtaining the early-age concrete properties needed for good concrete pavement performance. Attendees can expect to learn how to base their assessments of concrete on reliable measurements instead of empirical evaluation or "guestimates."

Session organizers Wayne Wilson, LarfargeHolcim, and Jussara Tanesi, SES Group & Associates LLC, received many interesting and timely abstracts, and they arranged for some of the associated articles to be published in *Concrete International*. This is one of the two articles included in this month's *CI*.

The term "setting" generally refers to a transition from fluid to solid-state.[1] In the case of cement-based materials, the driver for this transition is the hydration of portland cement, whereby lubricating paste becomes an adhesive as the microstructure of hydration products develops. Shear resistance grows in combination with the stabilizing effect of aggregate particles, leading to what is observed as increased stiffness or a decreased ability to deform fresh paste, mortar, or concrete.[2,3] ACI CT-13[4] defines "setting" as "a chemical process that results in a gradual development of rigidity of a cementitious mixture, adhesive, or resin." The same document defines "initial" and "final" setting times as "empirical values indicating the time required for the cementitious mixture to stiffen sufficiently to resist, to an established degree, the penetration of a weighted test device." This functional definition leaves plenty of room for interpretation ranging from the ASTM C403/C403M[5] criteria for initial and final setting based on resistance to pushing standardized probes into mortar, to the common association between concrete setting and the depth of the finisher's footprint in the field. A range of quantitative-to-qualitative and rigorous-to-ambiguous interpretation is evident in ACI documents.

In the 2014 Manual of Concrete Practice,[6] the term "setting" is used in 144 documents, collectively over 1000 times. In nine of those documents, the ASTM C403/C403M method is referenced, while one document (ACI 302.1R-04[7]) associates the stiffening of concrete and the proper timing of construction operations with footprint-depth. (The traditional "footprint test" meets the ACI CT-13 definition as resistance, "to an established degree," of "the penetration of a weighted test device," where the finisher is the test device, which as discussed later, is more "standard" than one would expect.) The vast majority of references to "setting" provide no details for implementation of ACI's definition, nor reference to other test methods. In some cases this may be intentional, given what may be a general, qualitative notion about how cement-based materials stiffen over time and how this impacts construction technique and in-place quality. This article

Table 1:

Proportions of concrete mixtures C1 and C2. Each mixture had a slump of about 25 mm (1 in.) at 15 minutes after contact between water and cement

Ingredients	C1		C2	
	kg/m³	lb/yd³	kg/m³	lb/ yd³
Cement*†	380	639	377	634
Water	171	288	170	286
Fine aggregates‡	771	1297	638	1073
Coarse aggregates§	998	1679	1116	1877
Air, %	2.9		3.3	

*Cement was ASTM C150/C150M Type I, manufactured by Saylor division of ESSROC, with Vicat initial and final setting times of 2.4 and 3.0 hours

†"Normal consistency" per ASTM C187-11 was 25%

‡Specific gravity = 2.57 and FM = 2.99

§Specific gravity = 2.65 and No. 7 (1/2 in.) per ASTM C33/C33M-13

provides a comprehensive comparison of the stiffening behaviors of pastes, mortars, and concretes based on standard tests. These results are further compared to those obtained by field-oriented but nonstandard measures of the ability to consolidate, finish, and otherwise deform fresh concrete over time. Additional details are available in Reference 8.

Experimental Investigations

Two sets of samples of paste, mortar, and concrete were sequentially prepared from the same materials, batched within 11 minutes, and held at an ambient temperature of 23°C (73°F). Starting with the same paste in each case (that is, P1 and P2 were identical), two mortars (M1 and M2) were created with different paste-sand ratios. Different amounts of coarse aggregate were added to M1 and M2 to create concretes C1 and C2, both of which had the same paste volume fraction (29%) at the same water-cement ratio (*w/c*) of 0.45 (refer to Table 1).

Setting behavior of pastes and mortars was measured by the ASTM C191 (Vicat)[9] and C403/C403M (Proctor)[5] penetration tests, while the modified Proctor test proposed by Abel and Hover[10] was used to measure penetration resistance (PR) of concrete. This latter test method is similar in concept to the "weighted boot" of Suprenant and Malisch,[11] simulating typical foot pressure while walking with full body weight temporarily supported on one foot. While these tests were in progress, concrete stiffening was periodically monitored via several field-oriented methods. To quantify "compactability" (C-series tests), every 15 minutes a concrete vibrator was inserted 90 mm (3-1/2 in.) into a larger container of the same concrete and withdrawn and the surface observed to note whether the concrete had flowed back into the vibrator void. To monitor "finishability" (F-series), the concrete surface was periodically scored to a depth of 6 mm (1/4 in.) and then restored with a magnesium float to erase the marks. Finally, to measure "deformability" (D-series), the depth of the worker's bootprint was measured. Threshold criteria for multiple stages for each of these test series are summarized in Table 2.

Setting Behavior Measurement

Standard test methods

Based on standard test methods for penetration resistance, our key observations include:

- Figure 1(a) shows that the two batches of identical pastes (P1 and P2) evidenced virtually identical Vicat penetration responses over a 6.5 hour period after batching. Figure 1(b) shows both mortar and concrete penetration-resistance results obtained using ASTM C403/C403M (labeled simply C403) for mortar and the modified Proctor test for concrete. While the Vicat results for paste show varying depth of penetration for a fixed contact pressure, mortar and concrete results indicate continuously increasing contact pressure is required for a fixed depth of penetration. Changing only the paste-aggregate ratio of mortar M1 relative to M2 produced statistically significant differences between their ASTM C403/C403M PR results.[8] In contrast, stiffening over time of concrete mixture C1 cannot be statistically distinguished from that of C2, where both mixtures contained equal volume fractions of the pastes for which the Vicat data were collected. These results demonstrate that differences in mortar-setting indicated by ASTM C403/C403M are not always reflected in differences in setting in concrete;
- Vicat responses show little or no measurable development of paste-stiffening prior to what ASTM C403/C403M

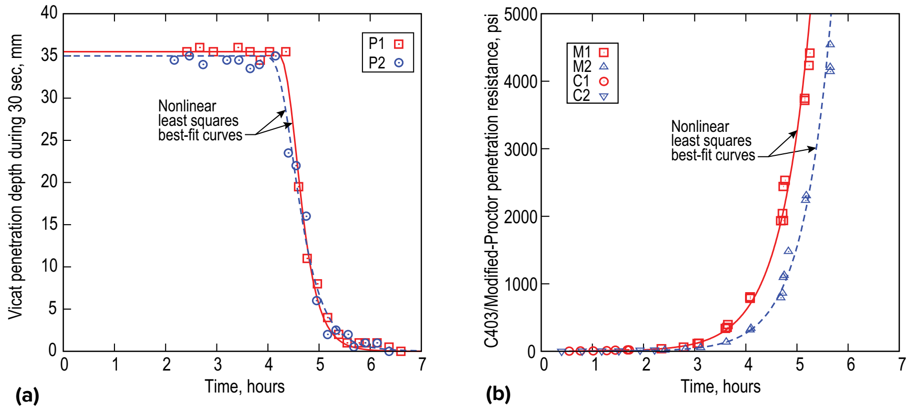

Fig. 1: Comparison of penetration test results for: (a) pastes P1 and P2; and (b) mortars M1 and M2 with concretes C1 and C2

Table 2:
Summary of results for penetration resistance tests and field-oriented test methods

Test method	Threshold label	Threshold criteria	Time at which threshold reached, hour*		Contact pressure when threshold reached, kPa (psi)†	
ASTM C191[9] (Vicat paste penetration)	Initial setting	25 mm (1 in.) penetration in 30 sec.	P1 = 4.53 P2 = 4.44		3450 (500) in paste fixed by apparatus	
	Final setting	0 penetration in 30 sec.	P1 = 6.60 P2 = 6.37		3450 (500) in paste fixed by apparatus	
ASTM C403/C403M[5] (mortar penetration)	Initial setting	3.4 MPa (500 psi)	Exponential M1 = 3.88 M2 = 4.36	Power M1 = 3.77 M2 = 4.22	3450 (500) in mortar	
	Final setting	27.3 MPa (4000 psi) in mortar	M1 = 5.13 M2 = 5.54	M1 = 5.23 M2 = 5.71	27,600 (4000) in mortar	
Concrete compactability (concrete C2 only)	C-I (C2)	Concrete effectively consolidated no void upon withdrawal of vibrator	Threshold begins C1 = N/A C2 = 0	Threshold ends C1 = N/A C2 = 1.29	C1 N/A	C2 14 (2) M_x 48 (7) MP_m 41 (6) CMC_i
	C-II (C2)	Partial void remains upon withdrawal of vibrator	C1 = N/A C2 = 1.29	C1 = N/A C2 = 2.93	C1 N/A	C2 282 (41) M_m 372 (54) MP_x 450 (65) CMC_i
	C-III (C2)	Void dia. = vibrator head dia. C-III ends at ASTM C403/C403M initial setting time = "vibration limit"[10]	C1 = N/A C2 = 2.93	C1 = N/A C2 = 4.36	C1 N/A	C2 3450 (500) M_m 2100 (321) MP_x 3800 (550) CMC_i
Concrete deformability	D-I (C1)	Depth of footprint ≥ 6 mm (1/4 in.) (one foot with full body weight over 5 sec.)	C1 = 0 C2 = 0	C1 = 0.85 C2 = 1.18	C1 21 (3) M_x 41 (6) MP_m 34 (5) CMC_i	C2 14 (2) M_x 41 (6) MP_m 34 (5) CMC_i
	D-II (C1)	3 mm (1/8 in.) ≤ depth of footprint ≤ 6 mm (1/4 in.)	C1 = 0.85 C2 = 1.18	C1 = 1.69 C2 = 2.22	C1 83 (12) M_m 150 (22) MP_m 160 (23) CMC_i	C2 90 (13) M_x 140 (21) MP_m 131 (19) CMC_i
	D-III (C1)	0 (not discernable) ≤ depth of footprint ≤ 3 mm (1/8 in.)	C1 = 1.69 C2 = 2.22	C1 = 3.10 C2 = 3.41	C1 920 (34) M_m 1220 (177) MP_x 1130 (164) CMC_i	C2 660 (95) M_m 680 (98) MP_x 920 (134) CMC_i
Concrete finishability	F-I	Magnesium hand-float could erase all footprints and voids or defects left by the vibrator used during C-II	C1 = 0 C2 = 0	C1 = 1.92 C2 = 2.34	C1 131 (19) M_m 210 (30) MP_x 190 (27) CMC_i	C2 103 (15) M_m 180 (26) MP_x 190 (27) CMC_i
	F-II	Magnesium hand-float could erase footprints but not deeper defects. Ends when no mark or defect restorable by hand-float	C1 = 1.92 C2 = 2.34	C1 = 3.10 C2 = 3.41	C1 924 (134) M_m 1220 (177) MP_x 1130 (164) CMC_i	C2 660 (95) M_m 675 (98) MP_x 920 (134) CMC_i

*P is paste; M is mortar; C is concrete

†M designates result obtained from regression curve fitted to mortar penetration resistance data acquired per ASTM C403/C403M; MP designates result obtained from regression curve fitted to concrete penetration resistance data acquired by modified Proctor test; and CMC designates result obtained from regression curve fitted to combined mortar and concrete penetration data. Subscript x designates result obtained by extrapolation from data obtained at higher or lower values of contact pressure; subscript m designates result obtained by direct measurement at a specific time or at designated threshold; and subscript i designates result obtained by interpolation from within a data set

Note: The 95% confidence interval for times obtained from PR tests as reported in this table are ±10, ±3, and ±7 minutes for concrete, mortar, and paste, respectively

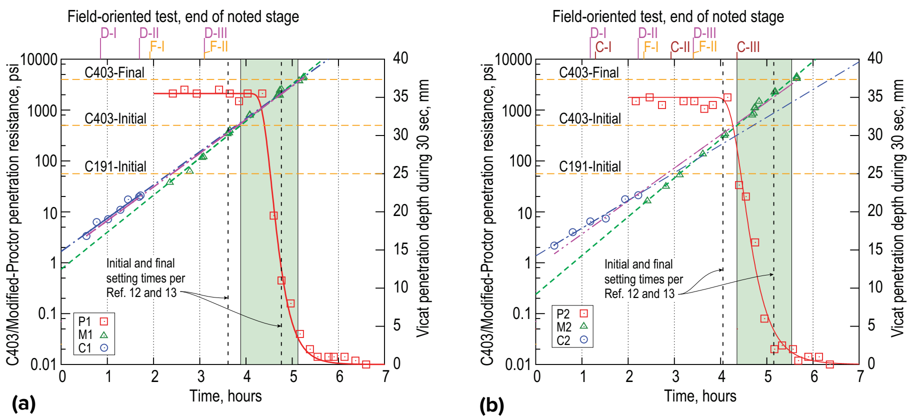

Fig. 2: Threshold times for field-oriented tests on concrete (compactability [C], finishability [F], and deformability [D]) and penetration data for paste, mortar, and concrete. Penetration data are for: (a) paste P1, mortar M1, and concrete C1; and (b) paste P2, mortar M2, and concrete C2

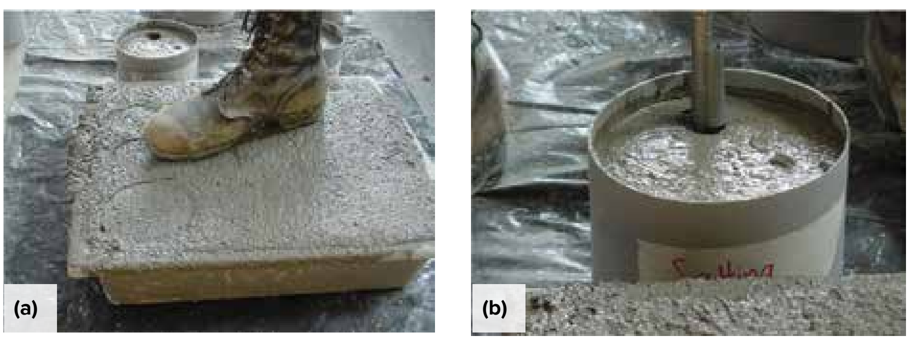

Fig. 3: Results from a field-oriented test on concrete do not necessarily correlate to results from a penetration test on a mortar mixture with the same water-cement and paste-sand ratio. In concurrent tests: (a) this concrete mixture exhibited no discernible footprint; and (b) its associated mortar mixture reached initial setting per ASTM C403/C403M

defines as "initial setting" of mortar.[5] Comparing P1 and M1 in Fig. 2(a), note the rapid change in Vicat paste stiffness during the interval between the ASTM C403/C403M initial and final setting times. Vicat "initial" setting of paste occurs about halfway between ASTM C403/C403M "initial" and "final" setting time. In contrast, Fig. 2(b) shows that M2 (higher paste content and delayed setting compared to M1) reached ASTM C403/C403M "initial" setting within 6 minutes of initial setting of its paste component, P2; and

- Mortars M1 and M2 reached ASTM C403/C403M "final" setting times of 1.4 and 0.9 hours, respectively—earlier than Vicat "final" setting time of paste.

Field-oriented tests

Based on field-oriented test methods, our key observations include:

- Figure 2(a) shows that the time at which an approximately 6 mm (1/4 in.) deep footprint could be impressed (end of Stage D-I) occurred more than 3 hours before ASTM C403/C403M initial setting. In fact, as shown in Fig. 3, the concrete surface could no longer be deformed or depressed by standing on it (end of stage D-III) 0.5 to 0.75 hour prior to ASTM C403/C403M initial setting. By this same margin of 0.5 to 0.75 hour prior to ASTM C403/C403M initial setting, the concrete surface could no longer be manipulated with a hand-float (end of F-II). When comparing M1 and C1, ASTM C403/C403M final setting of M1 did not occur until more than 1.5 hour after the C1 surface could no longer be indented or restored with the float. The same general results were obtained for concrete C2 and mortar M2;
- Figure 2(b) shows the ends of the time periods over which the C2 concrete mixture could be consolidated with the vibrator, at effectiveness levels C-I, II, and III (Table 2). The end of Stage C-I marks the limit of the ability to thoroughly consolidate the concrete with the vibrator and to re-fill the vibrator void as required for thorough consolidation by ACI 309R-05.[14] This stage was reached at about the same time a 6 mm footprint could be left, and about 3 hours prior to ASTM C403/C403M initial setting. This observation is in contrast to the traditional association of ASTM C403/C403M initial setting with Tuthill and Cordon's "vibration limit,"[15] originally defined not as the time limit for effective consolidation, but by the time limit at which an operating vibrator will no longer penetrate the concrete by its own weight. Given this discrepancy between the ability to thoroughly compact the concrete and the Tuthill and Cordon "vibration limit,"[15] the concept of a "consolidation limit" may be more useful, as characterized by the far earlier time beyond which the vibrator cannot close its own void upon withdrawal. Dodson[16] likewise endorsed application of BS 5075-1:1982,[17] suggesting that concrete should be placed and compacted at a mortar penetration resistance achieved about 1-1/2 hours prior to the ASTM C403/C403M initial setting values obtained here, or at about the endpoint of the authors' stage C-II. (The BS 5075-1:1982 limit still overestimates the length of time over which the concrete tested here could be thoroughly consolidated with a vibrator.);
- The ability to impress a 6 mm deep footprint in the concrete surface approximately coincided with a modified Proctor penetration resistance of about 41 kPa (6 psi) on concrete. (One can arrive at about the same penetration resistance by extrapolating the results of the ASTM C403/

C403M mortar test backwards, as shown by Abel and Hover.[10]) Any way it was measured, the end of the ability to effectively consolidate this concrete with a vibrator corresponded to the time that hand- or power-floating could begin (per ACI 302.1R-04), and about 3 hours prior to ASTM C403/C403M initial setting. This makes sense from a field perspective: finishers can begin power-troweling at about the time that they leave a 6 mm footprint, and it would not be reasonable to re-insert a vibrator at any later time; and

- Interestingly, a penetration resistance threshold of about 41 kPa in concrete is a reasonable estimate of contact pressure between a typical worker's boot with one foot statically in full contact with freshly cast concrete. This is supported by a general correlation between body weight and shoe size.[10,18,19] While this encourages use of a 6 mm footprint as a convenient indicator of PR in fresh concrete, in actual practice this index can be far less precise as addressed with technical skill and satirical effectiveness by Suprenant and Malisch.[20] Complicating factors beyond the individual validity of the body weight/shoe size relationship include whether the footprint was made while walking (one foot with dynamic effects) or while standing with weight evenly distributed, the rate at which the concrete deformed and the actual depth of penetration, and influence of boot tread on changing contact pressure with penetration depth. This is further complicated with the precision with which one measures (or more likely, estimates by eye) the depth of penetration, and whether that depth is uniform over the entire print or, as is likely, is deeper at the heel or ball of foot. That the footprint indicator has been useful for many years is evidence that individual finishers have consciously or unconsciously limited many of the variables to generate a personal correlation between the finisher's own footprints and the behavior of concrete, in accordance with Suprenant and Malisch's advice.[20] However, regardless of whether indicated by modified Proctor PR of 41 kPa in the concrete, or Bury's proposed 340 kPa (50 psi) in mortar per ASTM C403/C403M,[21] or Dodson's endorsement of the British Standard test criteria of 500 kPa (72 psi),[16,17] or by an approximate 6 mm depth of footprint, the time to begin finishing operations would have arrived at least 1.5 hours before the ASTM C403/C403M time of initial setting. For both concrete mixtures tested, ASTM C403/C403M initial setting took place 0.75 to 1 hour after the point at which no discernable footprint could be impressed on the concrete surface (end of D-III). This is virtually identical to Dodson's observation that: "The concrete finishers had done their job and moved onto another job site some 60 minutes before the [ASTM C403/C403M mortar] sample exhibited [ASTM C403/C403M] initial set."[22]

Discussion and Conclusions

Based on the test data, the following conclusions can be drawn:

- ASTM C403/C403M is not only a robust and reliable test method for monitoring the continuous stiffening of mortar with time but it is also currently the only U.S. standard method for quantifying setting behavior of "concrete" (as inferred from the PR of mortar sieved from that concrete). As shown here and by others[8,23] (including the developers of the ASTM C403/C403M method itself[15]), there is a critical need to distinguish between the setting behavior of concrete and the setting of its mortar fraction. This is recognized by ASTM C403/C403M in its dual statements that the method "covers the determination of the time of setting of concrete," and the caveat that: "This test method is suitable for use only when tests of the mortar fraction will provide the information required."[5] The key question is: "When or under what circumstances does the behavior of the mortar fraction provide the information required?";
- There is clearly a general relationship between mortar and concrete setting behavior, as both are driven by hydration of cementitious materials in the paste, as influenced by the stability provided by aggregates.[3,13,24] Additionally, as shown by Abel and Hover,[10] in many cases the ASTM C403/C403M PR curve for mortar can be seen as an approximate continuation of the PR curve for concrete determined by the modified Proctor test. While such a general relationship suggests the ability to predict concrete setting from mortar setting, an example reported herein suggests that such predictions are not always reliable. Mortars M1 and M2 had different volume fractions of the same paste and exhibited statistically different setting behavior. Concretes C1 and C2 incorporated these same mortars but adjusted total aggregate content to have identical paste volume fractions in the concrete and exhibited statistically indistinguishable setting behavior. This suggests that while the paste fraction may influence concrete setting more than the mortar fraction, the current Vicat test does not provide enough detail early enough in the process to explore this connection.[25] Another challenge with using mortar tests to predict concrete setting is that for field operations, stiffening of the concrete occurs literally hours earlier than mortar (based on ASTM C403/C403M criteria and definitions), so that tests of mortar extracted from a concrete batch cannot be used to predict behavior of that batch in real-time;
- The primary issue, therefore, is that ASTM C403/C403M criteria and definitions for initial and final set do not necessarily designate stages of concrete setting that dictate when key construction operations must take place, nor do the ASTM C403/C403M labels "initial" and "final" setting coincide with other common field interpretations of those same terms. Such differences can be rectified by correlating key thresholds identified for concrete in the field against the continuous background of increasing PR of mortar or concrete, as done in Fig. 2. For example, such tracking led to recognition of a "consolidation limit"—that is, the time beyond which concrete cannot be effectively consolidated with a vibrator. This threshold is certainly no later than the time at which power-floating can begin, and several hours prior to ASTM C403/C403M initial setting, which, ironically, was originally identified as the "vibration limit"[15];
- Standard industry documents make reference to concrete "setting" in at least three contexts: (a) strictly quantitative in accordance with ASTM C403/C403M, or some other prescribed method; (b) semi-quantitative as in references to depth of footprints; and (c) qualitative with general, nonspecific reference to the stiffening or "setting" of concrete over time. Writers of these documents should revisit their guidance or provisions in light of the results presented herein and in the literature to ensure that their wording will unambiguously lead to intended results. When preparing industry guides or specifications requiring that various construction operations begin or end at particular stages of concrete setting, it is important to quantitatively define such requirements as measurable via relevant tests. A meaningful test may include ASTM C403/C403M as performed on mortar but with field-oriented threshold values other than ASTM C403/C403M thresholds for initial and final set of mortar. A test performed directly on concrete, such as discussed herein or developed by others,[23] may be a useful alternative; and

- This research was initially aimed at clarifying the differences in setting behaviors of pastes, mortars, and concrete for applications in the lab and field. For future research, it remains to more fully explore the influence of mixture ingredients, proportions, admixtures, cementitious materials, and temperature on the interrelation of setting behaviors of pastes, mortars, and concretes.

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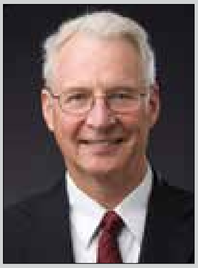

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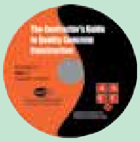

American Society of Concrete Contractors

Position Statement #43

Concrete Industry Tolerances for ADA/ABA Work

Standards issued under the Americans with Disabilities Act (ADA) and the Architectural Barriers Act (ABA) address access walkways and ramps to buildings and sites in new construction and alterations. The running slopes and cross slopes of walkways and ramps are being measured for compliance with these standards months or even years after completion. These evaluations typically do not include consideration of tolerances on slab surface finish—tolerances that the concrete industry has had in place for decades. Also, the measurements include changes in surface profiles caused by factors outside of the control of the concrete contractor, such as movements associated with concrete shrinkage and curling, temperature changes, and soil settlement or heave.

Section 5.8—Surface accessibility, of ACI 117.1R-14, "Guide for Tolerance Compatibility in Concrete Construction," provides this discussion: "'Americans with Disabilities Act and Architectural Barriers Act Accessibility Guidelines' (ADA/ABA-AG) states that all dimensions are subject to conventional industry tolerances except where the requirement is stated as a range with specific minimum and maximum end points. Where a requirement is a minimum or a maximum dimension that does not have two specific minimum and maximum end points, tolerances may apply."

Other "conventional industry tolerances" for slab finishes are discussed in the following resources:

- ACI 117-10 (Reapproved 2015), "Standard Specification for Tolerances for Concrete Materials and Construction";
- ACI 302.1R-15, "Guide to Concrete Floor and Slab Construction";
- ACI 301-16, "Specifications for Structural Concrete"; and
- "Movements that Affect Tolerance Measurements," *Concrete International*, ACI, July 2016.

ACI 117-10 requires that if an unleveled straightedge placed on the slab surface is used to measure surface tolerances to evaluate the concrete contractor's workmanship, such measurements must take place within 72 hours after slab placement. ACI 117-10 and ACI 302.1R-15 present the rationale for this requirement—slab surfaces change or move with time. ACI 117 has included a time limit on the measurement of surface quality for over 25 years. However, walkways and ramps are typically measured for conformance with the ADA/ABA guidelines months or even years after completion of the work. This would be in violation of standard concrete industry practice for acceptance of the concrete contractor's workmanship.

Industry-established tolerances include a plus and minus variation. Specifying a slope at a maximum provides only a minus tolerance and thus eliminates half of the tolerance available to the concrete contractor in conventional industry tolerances. Additionally, designing slopes at the maximum or minimum limitations can also eliminate or restrict elevation and location tolerances of adjoining concrete elements.

While many publications discourage designing at the maximum or minimum, some specifiers ignore this recommendation. To mitigate this practice, ACI 117.1R-14 recommends specified slopes that allow for tolerances on the ramps and sidewalks and for adjoining elements. This document states the design strategy as: "The general practice is to specify a dimension less than the required maximum (or more than the required minimum) by the amount of the expected field or manufacturing tolerance. Where ADA/ABA-AG requirements give a dimensional range, it is good practice to specify a dimension between the range." ACI 117.1R-14 recommends a maximum overall design running slope of 1:25 (4%) for walks and other nonramp exterior pedestrian surfaces; a maximum overall design running slope of 7.5% for exterior accessible ramps; and a maximum design cross slope for walks, accessible exterior ramps, and other pedestrian paving of 1.5%.

ASCC concrete contractors will work with Owners, Design Team Members, and Construction Managers to comply with ADA/ABA requirements. However, as stated in the ADA/ABA-AG guidelines, ASCC concrete contractors are entitled to the application of conventional industry tolerances. Concrete contractors will correct nonconforming work that is designed in accordance with ACI 117.1R-14 recommendations and measured within 72 hours after installation. If you have any questions, contact your ASCC concrete contractor or the ASCC Technical Hotline at +1.800.331.0668.

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Vertical Concrete Polishing Inc.

Innovation in Vertical Concrete Polishing

New design opportunities are created

Although it's possible to produce a polished vertical concrete surface using handheld grinders, these finishes can be uneven if large areas must be polished. So until now, designers who wanted their projects to include large expanses of polished concrete walls have been limited to using plant-cast and site-cast precast concrete pieces that were polished before they were erected. Unfortunately, when large panels are required, the risk of stress cracking looms large.

The designers of Faena House, an 18-story condominium complex in Miami Beach, FL, called for 40,000 ft^2 (3700 m^2) of polished, cast-in-place structural concrete walls in the building. But after estimates showed that the laborious process of hand polishing would have taken more than 2 years, the owners of the complex sought a different solution.

They contacted Mark Richardson, an inventor with a flooring background, at his machine shop in Carrollton, GA, and presented him with the problem of polishing 40,000 ft^2 of 30 ft (9 m) tall walls. Five weeks later, Richardson drove his prototype solution—an automated machine that can grind and polish vertical surfaces—to the jobsite, and he polished a test area of 50 ft^2 (4.5 m^2) to a brilliant glasslike 1500 finish in 8 hours. A test area of that size would take a week to complete with hand grinders. This led to a signed contract within days. Richardson and his Project Manager Patrick Durkin, who has a construction background, went back to Georgia and built six improved polishing machines.

Examples of the surface imperfections in the walls

Overcoming Jobsite Challenges

When they started the job in February of 2014, the polishing team faced multiple challenges. The walls that the concrete contractor had placed were cured and ready to be polished, but when the forms were stripped, the surfaces were far from uniform; some were severely bowed from forms that had flexed. Richardson returned to his shop and built a new machine that removed a lot of material quickly but was gentle enough to not gouge or scar the wall. It was just aggressive enough to cut the wall true and plumb to provide a polishable surface.

Another obstacle was the problem of ledges that were left in the walls from forms that shifted during the concrete placement. Some of the ledges had to be ground flat and then blended in with the rest of the wall, sometimes 10 to 12 ft (3 to 3.6 m) in all directions. Design elements also posed challenges. There were rows of columns to be polished, and some of the columns were only 8 in. (200 mm) apart. A thinner apparatus was designed to fit in between the closely spaced columns. Other customizations were needed to accommodate curved walls and inside corners, so the equipment was changed and upgraded throughout the project as needed.

On site, the workers came up with ideas to make the job easier, and Durkin found ways to increase production. At first, two workers were required to operate a machine. After some automation was added, the equipment was able to move horizontally and vertically on its own, and so only one

Polished structural elements at Faena House, Miami Beach, FL

operator was needed. Durkin communicated each day on the phone with Richardson, who would then take the information and create new prototypes in Georgia. Those were shipped and tested in the field and Durkin would make minor adjustments, if necessary. With teamwork, Richardson and Durkin were able to balance production and the development of new equipment as needed to adapt to each changing phase of the project. "Amazingly, most of the ideas worked very well, held up throughout the project, and are still being utilized today," Richardson says.

A Polishing Option

With perseverance and a 6-day-per-week work schedule, the job was completed in 1 year (on schedule) with a crew of only 10. "The machines are so easy to operate that I did not need to hire employees with polishing or even concrete experience. The average worker was able to be trained and put in charge of polishing walls in as little as a few days. All you need is a little common sense," Durkin explains.

Richardson and Durkin are now business partners in Vertical Concrete Polishing, Inc., which works both domestically and internationally to fill the need for large, cast-in-place, polished concrete walls. Although the patent-pending vertical polishing equipment is not being sold at this time, the company leases equipment that's designed specifically for each project. They provide a project strategy and come to the jobsite to train the crew to run the equipment efficiently—a more affordable option for someone wanting this very modern finish or a new branch of services to offer.

For the work at Faena House, the company was presented the 2015 Hanley Wood Innovation Award for Polished Concrete at World of Concrete 2016.

—Vertical Concrete Polishing, Inc.
www.verticalconcretepolishing.com

Selected for reader interest by the editors.

Self-Annealing Concrete

Improving concrete performance with autocatalytic cement and pozzolanic reaction

by Romeo I. Ciuperca

Concrete is one of the most ubiquitous and versatile building materials, but it faces several challenges. These include the need to reduce the overall carbon footprint of concrete while at the same time making concrete more durable and less prone to cracking. In addition, these challenges need to be met without significantly increasing the in-place cost of concrete or slowing construction times.

The main purpose of concrete forms is to provide leak-free molds for plastic concrete. Concrete formwork is usually not insulated and is removed as quickly as possible. Early in its curing history, concrete is therefore exposed to ambient temperatures and relative humidity levels. The hydration reaction of portland cement generates substantial heat in the first 10 to 24 hours after it's mixed with water, and the temperature of placed concrete generally reaches its peak within the first 10 to 16 hours. If the concrete is not insulated during and after this time period, heat can be rapidly lost to the environment, allowing the surface concrete to cool to ambient temperature levels generally within the first 16 to 36 hours. Unfortunately, the concrete typically has not gained sufficient strength to withstand the resulting tensile strains near the exposed surface, thus creating an environment for microcracking. Often, this thermal shock is in tandem with the loss of curing moisture, further exacerbating cracking. By insulating the formwork, however, heat and moisture loss to the environment can be slowed greatly—they therefore remain in the concrete and accelerate the hydration process. In addition, thermal and moisture differentials can be minimized, reducing tensile strains near the concrete surfaces. We term this effect self-annealing, as it improves the performance of the concrete by providing:

- Reduced cracking; and
- Accelerated strength gain in mixtures with high percentages of alternative or supplementary cementitious materials (ACM or SCMs, respectively).

Reduced cracking lowers the risk of additional damage associated with water, deicing chemicals, and carbonation. Mixtures with higher ACM and SCM contents have reduced calcium hydroxide ($Ca(OH)_2$) content and thus reduced permeability and lower risk of alkali-aggregate reactions. And the benefits of the self-annealing process are gained at potentially lower cost, lower embodied energy, and reduced CO_2 footprint.

The Self-Annealing Process

Formwork

The self-annealing process requires formwork that will slow the rate of heat loss from the concrete. U.S. Patent 8,545,749 describes in detail several requirements for the formwork, as well as preferred cementitious material compositions.[1] The typical R-value required for the insulated forms is between 1.5 and 16 h·ft^2·°F/Btu (0.26 to 2.8 m^2·K/W). Alternatively, a plastic insulation board can be used as a liner between a conventional formwork sheathing board and the concrete. Insulation in direct contact with the concrete will retain heat and moisture better than insulating blankets over conventional formwork. Also, an insulation board can remain in place as the conventional formwork is stripped, preventing the concrete from cooling rapidly. The insulation can be removed later, after the concrete has cooled to ambient temperature or achieved the desired properties. Alternatively, the insulation can remain attached to the final concrete product, providing insulation to the completed structure. In the latter case, the R-value can be 19 h·ft^2·°F/Btu (3.3 m^2·K/W) or higher.

Autocatalytic reaction

Narmluk and Nawa[2] studied the effects of temperature on the hydration of concretes with 25 and 50% replacement of portland cement with Class F fly ash. They found that the hydration kinetics occurred in three stages. $Ca(OH)_2$ slowly diffuses through the dense glass wall of the fly ash during

Stage 1, followed by a rapid reaction of the $Ca(OH)_2$ with the fly ash in Stage 2. The reaction slows in Stage 3, as the reaction products from Stage 2 restrict the diffusion of $Ca(OH)_2$ to the unreacted fly ash. The research showed that the initiation time (the Stage 1 period) was reduced with increasing temperature, and that the overall pozzolanic reaction increased with increasing temperature. A higher curing temperature results in a more rapid production of $Ca(OH)_2$ from cement hydration, and in turn, the increased heat generated through cement hydration allows the $Ca(OH)_2$ to react more quickly with the fly ash in the mixture.

To minimize the potential for delayed ettringite formation (DEF), the concrete temperature during curing should be kept below 60 or 70°C (140 or 158°F) in mixtures without and with SCMs, respectively. If temperatures exceed these values, there is an increased risk that monoaluminasulfates formed during the curing process will convert to ettringite over time when the concrete is at a lower temperature.[3] For mass concrete placements, the maximum temperature is controlled by precooling the concrete and/or cooling the placed concrete as well as using mixtures with high SCM contents. For thinner sections cast in insulated formwork, the maximum temperature can be controlled by reducing the thermal resistance (R-value) of the insulation.

Another concern of higher-temperature curing is that the ultimate strength of the concrete may be reduced even though early age strengths are higher. This is typically seen for concrete without SCMs.[3] Less is known about concretes with SCMs, but work by Ozyildirim[4] indicates that concrete mixtures with SCMs cured at elevated temperatures for several days have higher strengths than similar mixtures cured under lower temperatures. Our studies have shown that this effect is true even if maximum curing conditions are above the 38 to 50°C (100 to 122°F) temperature range used by Ozyildirim.[4]

Ozyildirim[4] further showed that an early period of curing at 38°C or higher temperatures enhances the durability of concrete containing SCMs but does not enhance the long-term properties of portland cement concrete. This suggests that self-annealing provides enhanced benefits for concrete with a high percentage of SCMs.

The self-annealing process uses the heat generated by the cement hydration reaction, resulting in an autocatalytic reaction where the temperature is elevated until most cement particles are hydrated. The cement hydration rate is increased to more fully hydrate cement at an early stage. The autocatalytic reaction produces more $Ca(OH)_2$ early on for reaction with SCMs, and the higher concrete temperatures increase the SCM's reaction rate. Moisture retention and more uniform temperature in the concrete minimizes shrinkage and thermal stresses.

Field Data

Tests have been conducted to compare the performance of concrete placed in insulated formwork against concrete placed in conventional formwork. Tested concrete mixtures have contained fly ash and/or slag cement. Our examples show that the self-annealing process associated with insulated formwork results in increased maximum curing temperature, decreased diurnal temperature variations, and increased early and long-term compressive strengths.

Example 1

Figure 1 shows the surface temperature versus time data for a concrete mixture placed in insulated formwork and in conventional formwork. The ambient temperature is also shown. The 80/20 mixture comprised 540 lb/yd^3 (320 kg/m^3) portland cement and 120 lb/yd^3 (70 kg/m^3) fly ash and was produced with a water-cementitious material ratio (*w/cm)* of 0.42. The concrete was placed in conventional vertical frames with plywood forms creating 8 in. (200 mm) thick wall elements. The Composite Insulated Forms used 4 in. (100 mm) thick insulation board with an R19 insulating value on each side. Strength tests were made using conventional 4 x 8 in. (100 x 200 mm) test cylinders and cores taken from the concrete panels.

The daily temperature variations for the concrete placed in the insulated formwork are significantly lower in magnitude than those for the concrete placed in the conventional formwork. Also, the temperature of the concrete placed in the insulated formwork takes nearly 2 weeks to reach the average ambient temperature. While the maximum temperature for the self-annealing concrete didn't exceed 60°C, it was significantly higher than the maximum temperature of the concrete in the conventional formwork.

The strength data for the concrete are provided in Table 1. Lab cylinders were made and cured according to ASTM C39/C39M, "Standard Test Method for Compressive Strength of

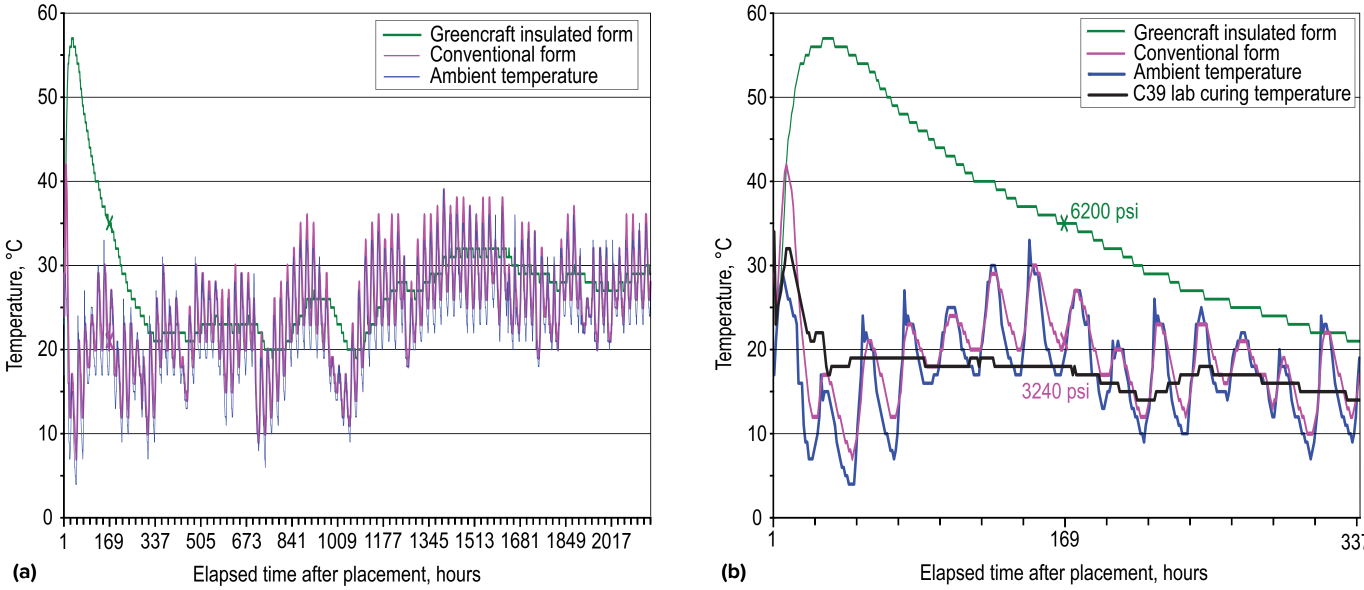


Fig. 1: Comparison of surface temperatures for 80/20 concrete mixture placed in conventional formwork and insulated formwork: (a) measurements taken over a 90-day period; and (b) measurements taken during the initial 14 days after placement, including data measured in a lab-cured test cylinder (Note: °F = 1.8 × °C + 32)

Cylindrical Concrete Specimens." Core samples taken from the conventional and insulated concrete elements followed the protocol in ASTM C42/C42M, "Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete."

The self-annealing concrete exhibited very rapid early-age strength gain. In contrast, the same concrete mixture placed in conventional formwork exhibited slow strength gain. At 90 days and 14 months after placement, the self-annealing concrete had higher compressive strength than the concrete placed in conventional formwork. While moist-cured laboratory cylinders had higher 90-day compressive strength than the self-annealing concrete, the strength values do indicate the value of retaining moisture and minimizing temperature swings.

Table 1:
Compressive strength data over time for 80/20 concrete mixtures

Form/curing type	Compressive strength, psi				
	8 Days	28 days	58 days	90 days	14 months
Conventional formwork	3240	4660	5640	6190	6810
ASTM C39/C39M lab-cured test cylinders	3170	5555	5960	7360	n/a
Self-annealing concrete formwork	6180	6610	6860	6890	7980

Note: 1 psi = 0.007 MPa

Example 2

Figure 2 shows the long-term temperature data for a 34/33/33 concrete mixture comprising 220 lb/yd³ portland cement, 215 lb/yd³ fly ash, and 215 lb/yd³ slag cement (130, 128, and 128 kg/m³, respectively). The *w/cm* for the mixture was 0.41. This is a mixture that would normally be restricted to mass concrete applications due to the low cement content.

As in Example 1, the daily temperature variation was significantly reduced for the self-annealing concrete. Also, the initial increase was greater and the subsequent decrease in temperature slower for the self-annealing concrete placement. The self-annealing concrete also remained significantly below 60°C, as the concrete was placed in a thin element.

Table 2 provides the corresponding strength data for the concrete in Fig. 2. As was the case of the mixture with only fly ash substituted for portland cement, the early strength development

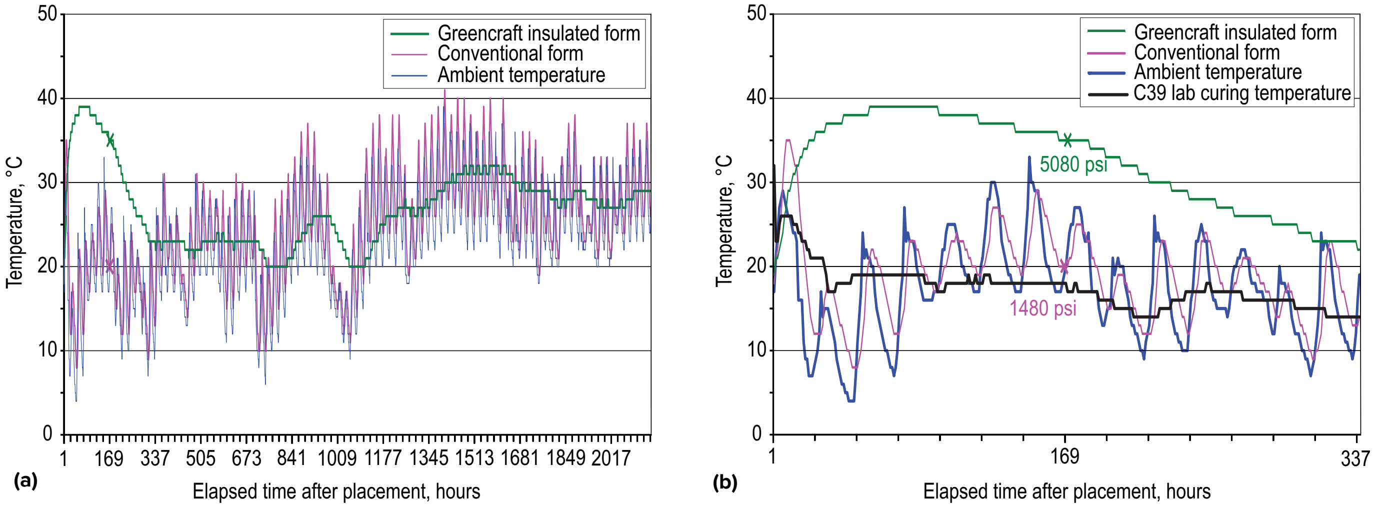


Fig. 2: Comparison of surface temperatures for 34/33/33 concrete mixture placed in conventional formwork and insulated formwork: (a) measurements taken over a 90-day period; and (b) measurements taken during the initial 14 days, including data measured in a lab-cured test cylinder (Note: °F = 1.8 × °C + 32)

Table 2:
Compressive strength data over time for 34/33/33 concrete mixture

Form/curing type	Compressive strength, psi				
	8 days	28 days	58 days	90 days	14 months
Concrete in conventional formwork	1470	3930	4850	5635	5830
ASTM C39/C39M lab-cured test cylinders	980	3830	6530	7310	n/a
Self-annealing concrete formwork	5080	5880	6230	6640	7520

Note: 1 psi = 0.007 MPa

and the longer-term strengths were greater for the self-annealing concrete relative to the concrete placed in conventional formwork.

The slow strength development of this mixture using conventional formwork makes it unsuitable for use in many field applications, whereas the self-annealing concrete achieved good strength after 1 week. In summary, these examples show that the self-annealing process can be used to meet early and long-term strength requirements when using concrete mixtures with high cement replacement levels.

Sustainability and Modeling

Because the self-annealing process produces good early and long-term strength at high cement replacement levels, concretes can be produced for structural applications with large reductions in portland cement content and thus reduced carbon footprints. Table 3 shows the carbon footprints for the two mixtures used in Examples 1 and 2 compared to a portland cement only mixture.

As indicated in the work by Ozyildirim,[4] these mixtures can be expected to have improved permeability versus concrete cured in conventional forms.

Conclusions

Insulated formwork results in a self-annealing process for concrete and offers the following benefits:

- Improved strength;
- Reduced temperature differentials and associated strains;
- Reduced permeability; and
- Enhanced ability to use mixtures with high ACM and SCM replacements levels.

Several of these benefits, such as increased strength and a lower carbon footprint, are readily verified and apparent. Additional work is needed to quantify the improved transport properties and reduced thermally induced cracking associated with self-annealing concrete so that these parameters can be incorporated into service life models for predicting the service life of structures subjected to chloride ingress and carbonation.

References

1. "Concrete Mix Composition, Mortar Mix Composition and Method of Making and Curing Concrete or Mortar and Concrete or Mortar Objects and Structures," U.S. Patent 8,545,749 B2, Oct. 1, 2013.

2. Narmluk, M., and Nawa, T., "Effect of Curing Temperature on Pozzolanic Reaction of

Table 3:
CO_2 reduction enabled by self-annealing concrete

Mixture type	CO_2 per ingredient, lb/lb	Amount of ingredient in concrete batch, lb/yd³	Amount of CO_2 associated with ingredient in concrete batch, lb/yd³	Total CO_2 in concrete batch, lb/yd³	CO_2 reduction relative to conventional mixture, %
Conventional					
Portland cement	0.85	650	552.5	552.5	—
80/20					
80% portland cement	0.85	540	459	471	14.75
20% Class F fly ash	0.10	120	12		
34/33/33					
34% portland cement	0.85	220	187	238.6	56.81
33% Class F fly ash	0.10	215	21.5		
33% slag cement	0.14	215	30.1		

Note: 1 lb = 0.45 kg; 1 lb/yd³ = 0.59 kg/m³

Fly Ash in Blended Cement Paste," *International Journal of Chemical Engineering and Applications,* V. 5, No. 1, Feb. 2014, pp. 31-35.

3. Collepardi, M., "Chapter XIV - Temperature and Concrete," *The New Concrete*, Grafiche Tintoretto, Italy, 2006, 421 pp.

4. Ozyildirim, H. C., "Effects of Temperature on the Development of Low Permeability in Concretes," *VTRC 98-R14*, Virginia Transportation Research Council, Charlottesville, VA, 1998, 22 pp.

—Greencraft, LLC, **www.greencraftllc.com**

Note: Additional information on the ASTM standards discussed in this article can be found at **www.astm.org**.

Selected for reader interest by the editors.

ACI member **Romeo I. Ciuperca** is the Founder of Greencraft, LLC. He has 25 years of experience as a specialty contractor in the commercial construction industry and has completed projects totalling over $100 million in value. His passion to improve efficiency in construction has led to the development of highly energy-efficient building envelope systems and self-annealing accelerated concrete curing systems. He has designed solutions that are the subject of 22 U.S. patents, over 40 pending U.S. and foreign patent applications, and 25 trademarks. He is now in the process of taking Greencraft technology to market.

What's New from ACI

TECHNICAL DOCUMENTS

Specifications for Structural Concrete—ACI 301-16

This is a Reference Specification that the Architect/Engineer can apply to any construction project involving structural concrete by citing it in the Project Specifications. A mandatory requirements checklist and an optional requirements checklist are provided to assist the Architect/Engineer in supplementing the provisions of this Specification as required or needed by designating or specifying individual project requirements.

Guide to Shotcrete—ACI 506R-16

This guide is a companion document to ACI 506.2, "Specification for Shotcrete," and provides information on materials and properties of both dry-mix and wet-mix shotcrete. Most facets of the shotcrete process are covered, including application procedures, equipment requirements, and responsibilities of the shotcrete crew.

ACI 506R-16 and 506.2-13 are now available in the ACI webstore for a discounted package price.

Code Requirements for Assessment, Repair, and Rehabilitation of Existing Concrete Structures (ACI 562-16) and Commentary—ACI 562-16

This code provides minimum requirements for assessment, repair, and rehabilitation of existing structural concrete buildings, members, systems, and where applicable, nonbuilding structures. ACI 562-16 was specifically developed to work with the International Existing Building Code (IEBC) or to be adopted as a standalone code.

ACI UNIVERSITY ONLINE COURSES

Aggregates for Concrete (Part 1)

Learning objectives:
1. Aggregate quantities typically used in concrete;
2. Size, distribution, and moisture content of aggregates;
3. Calculating fineness modulus;
4. Determining nominal maximum size aggregate; and
5. Calculating water-cementitious materials ratios.

Continuing Education Credit: 0.1 CEU (1 PDH)

Aggregates for Concrete (Part 2)

Learning objectives:
1. Calculating bulk density;
2. Impact of size, shape, and texture of aggregates on workability;
3. Organic impurities in aggregates and their impact on concrete;
4. Minimizing effects of alkali-aggregate reaction in concrete; and
5. Proper sampling of aggregates.

Continuing Education Credit: 0.1 CEU (1 PDH)

Products &

Practice

Ashford Formula

Ashford Formula is a transparent, chemically reactive, water-based sealer that penetrates concrete and masonry building materials. The formula penetrates into concrete and locks the pores from within, providing a deep, permanent seal. Ashford Formula chemically reacts with the salts in the concrete, increasing the density, toughness, and hardness. The sealer progressively penetrates the concrete and stops efflorescence and the leaching of lime and alkalis. Ashford Formula contains no silicone and is coatable and compatible with any type of covering.

—Curecrete Distribution, Inc., **http://curecrete.com**

Platinum 880 VOC

Cresset Chemical Company's Platinum 880 VOC is the first release agent available in the Platinum line. It is environmentally friendly, nontoxic, and biodegradable. Cresset Platinum is made with high-quality virgin components and contains no waxes, silicones, or solvents. The proprietary formula is nonstaining and odorless, using a nonpetroleum, nonvegetable lipophilic material as its base component. This release agent can be used in most temperatures. It is packaged ready-to-use and can be applied in advance, from minutes or up to 2 weeks prior to the time the concrete is placed. Apply an ultra-thin film (0.0005 in. thick) to clean and dry forms by spraying, rolling, brushing, or wiping. The release agent doesn't interfere with adhesion of caulk, architectural coatings, paint, sealers, and curing compounds on cured concrete surfaces.

—Cresset Chemical Company, **http://cresset.com**

PF80 Potentiometer

The PF80 is a low-cost, battery-powered rotary potentiometer that can be used to monitor movements at cracks and joints. The onboard data logger can store up to 51,062 readings that can be downloaded to a personal computer via a USB (PF80-USB) or wireless interface (PF80-WIRELESS). The PF80 has a maximum stroke of 80 mm (3 in.). The units are simple to configure using a personal computer and the supplied Windows-based graphic user interface (GUI).

—Fiama Srl, **www.fiama.it/en**

Nearmap

Nearmap provides high-resolution orthogonal aerial imagery covering more than 50% of the U.S. population. It's used by thousands of organizations for project management, remote site surveys, business development, risk assessment, estimating, auditing, and enforcement. Using MapBrowser, a unique web-based platform for navigating through the imagery, organizations are able to see what is on the ground now, in great detail, and how it has changed over time. MapBrowser includes easy-to-use tools for measuring lengths, areas, and volumes as well as adding notes and shapes to the imagery. Nearmap collects new images about every 2 months. Its proprietary system also captures elevation data, allowing the generation of an accurate Digital Elevation Model that can be used for estimating volumes, determining the relative heights of objects, simulating the effects of shadows at any time of the year, and modeling flood scenarios.

—Nearmap, **http://go.nearmap.com**

Commander

ProAll's Commander Reimer Mixer is a volumetric mixer with automated functions and a digital interface that provide unprecedented control, accuracy, and consistency. Elements of a mixture are precisely measured several times a second, auto-controlled by a programmable logic controller (PLC) hydraulic system. Operators have total command of fully digital controls on one dashboard. All mixture measurements are displayed together on one screen where production can be tracked in real time and warning messages will appear if mixture proportions are incorrect.

—ProAll, **www.proallinc.com**

MOBILEconnect

Command Alkon's MOBILEconnect fully integrates with users' core software. It is a subscription-based service, enabling users to access information anytime, from anywhere. The proprietary EDX messaging platform quickly and accurately transfers data between applications, the cloud, and the user's network. The software provides updates on project, order, ticket, and truck information as they occur. There are five applications available: MOBILEcommerce® provides users the ability to access projects and order information directly; MOBILEjobsite™ application allows users to access real-time truck information or request new orders; MOBILEsales® allows sales staff to track bids, send quotes, and manage sales activities; MOBILEticket® is a real-time paperless ticketing solution. Signatures are collected electronically, then tickets are emailed directly to customers and back to the user's office; and supplyCONNECT™ provides users the ability to manage inventory across locations.

—Command Alkon, **www.commandalkon.com**

Ultrafine SD

US Grout, LLC's, and Avanti International's Ultrafine SD cementitious grout is certified by NSF International, conforming to the requirements of NSF/ANSI Standard 61 - Drinking Water System Components - Health Effects. Ultrafine's average particle size is 3 μm in diameter. Ultrafine grout is composed of a finely ground mixture of portland cement, pumice, and dispersant to penetrate fractures as small as 6 μm and as deep as 3 m (10 ft). It is typically used on large-scale projects requiring significant volumes of grout to be injected. It can be used for stabilizing and strengthening soil and sand; sealing seepages in mines, dams, tunnels, and sewer systems; fortifying waste containment facilities; squeeze-grouting and rehabilitating oil and gas wells; and forming low-permeability grout curtains.

—US Grout, LLC, **www.usgrout.com**

—Avanti International, **www.avantigrout.com**

CORK

T3 Construction Innovations' CORKs are safe, efficient, and permanent concrete forming tools. CORKs are used to form and repair core holes and other penetrations in concrete structures, and they are installed in horizontal and vertical applications. All of the tool's components are manufactured from steel and aluminum. Users install a threaded rod into CORK and insert CORK through a slab or wall. Then users slide the floor or wall applicator into position around the threaded rod and secure with a SpeedNut. Afterwards they install reinforcement per jobsite engineering specifications and fill the hole with the preferred concrete repair product. Once the product has hardened, users snap the threaded rod off at floor height.

—T3 Construction Innovations, **www.t3constructioninnovations.com**

Web Notes

ICPI Launches New Website

The Interlocking Concrete Pavement Institute (ICPI) launched a new, redesigned website with new features and content. Contractors, designers, and homeowners are able to access specific information needed by clicking on their designated portal. The website also features a redesigned Members Only page, providing meeting information, member news, and updates, as well as a member dashboard, where members can update their company information. The site includes a new search-by-proximity function, enabling users to find resources and services providers closest to their location.

—ICPI, **www.icpi.org**

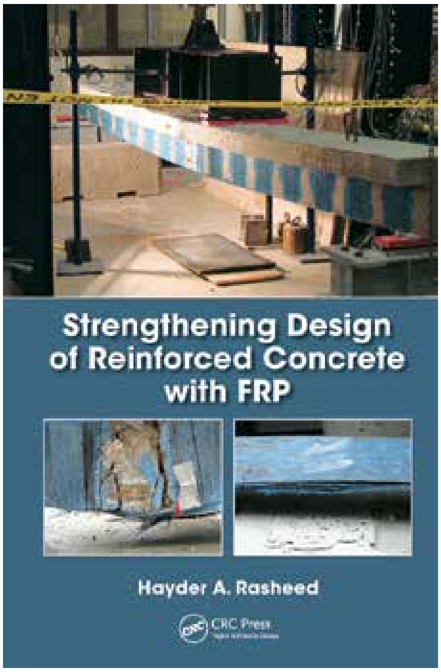
Book Notes

Strengthening Design of Reinforced Concrete with FRP
By Hayder A. Rasheed

Strengthening Design of Reinforced Concrete with FRP features strengthening design of reinforced concrete with fiber-reinforced polymer (FRP) beyond the abstract nature of design guidelines. This textbook addresses material characterization, flexural strengthening of beams and slabs, shear strengthening of beams, and confinement strengthening of columns; discusses the installation and inspection of FRP as externally bonded or near-surface-mounted composite systems for concrete members; contains shear design examples and design examples for each flexural failure mode independently, with comparisons to actual experimental capacity; presents innovative design aids based on ACI Committee 440 recommendations and manual calculations for confinement design interaction diagrams of columns; and includes end-of-chapter questions and references for further study. A solutions manual is available with qualifying course adoption.

—CRC Press, **www.crcpress.com**

Price: $149.95; 248 pp.; ISBN: 9781482235586



Products & Service Literature & Videos

Wagner Meters Service Temperature Correction Table

Wagner Meters shared a tool developed for contractors, flooring installers, and others in the concrete industry, enabling them to predict the relative humidity (RH) of a concrete floor slab at service conditions—even before those service conditions are met. The science-based method for measuring moisture in concrete (standardized as ASTM F2170) mandates taking RH measurements at service conditions. Sometimes project timelines are such that contractors would like to estimate RH before reaching service conditions. The Service Temperature Correction Table is a scientifically sound predictive tool developed by CTLGroup, a wholly owned subsidiary of the Portland Cement Association. It's available for contractors and others to use free of charge, courtesy of a special arrangement between Wagner Meters and CTLGroup.

—Wagner Meters, **www.wagnermeters.com**

—CTLGroup, **www.ctlgroup.com**

Product
Showcase

Curing Technologies

Gilson Perfa-Cure Curing Boxes

Gilson's Lightweight Perfa-Cure Curing Boxes provide storage and protection for concrete test specimens on the jobsite to meet current ASTM C31/C31M and AASHTO T 23 specifications for initial curing. Users simply plug in the unit and set the thermostat to the desired temperature. This line features models with heating or both heating and cooling functionality. A safe aluminum base radiates heat, and a blower fan circulates cool air inside the box. HM-491 Perfa-Cure provides heat only and accommodates up to nine 6 x 12 in. (152 x 305 mm) cylinders or thirty 4 x 8 in. (102 x 203 mm) cylinders. HM-493 Perfa-Cure Mini is heat-only and holds four 6 x 12 in. cylinders or ten 4 x 8 in. cylinders. HM-495 Perfa-Cure Plus features both heating and cooling functionality and accepts nine 6 x 12 in. or thirty-two 4 x 8 in. concrete cylinders.

—Gilson, **www.globalgilson.com**

Plasti Shield

Surface Shields' Plasti Shield is lightweight corrugated plastic sheeting that is used in the building and construction industry for floor and wall covering protection, countertop protection, temporary window and door replacement, and temporary clean room applications. This sheeting can be easily cut with a utility knife. Plasti-Shield can also be used as a dampproofing membrane, for filling construction expansion joints, as concrete formwork, as low-level thermal insulation, and as a packing medium. It is 100% recyclable, reusable, nontoxic, and resistant to chemicals. Plasti Shield is available in standard and fire-resistant sheets.

—Surface Shields, **www.surfaceshields.com**

L&M CURE R

LATICRETE's L&M CURE R™ is a dissipating resin membrane curing agent. This ready-to-use product is an effective curing membrane for use on normal concrete, shake-on hardeners, and new concrete toppings in commercial and industrial projects. The sprayable liquid maintains efficient water retention performance to comply with ASTM International, AASHTO, and most state departments of transportation requirements. L&M CURE R is a clear amber-colored resin that can be used on interior, exterior, horizontal, and vertical concrete applications.

—LATICRETE, **https://laticrete.com**

Sika UltraCure Blankets

Sika's UltraCure NCF™ and DOT™ natural cellulose fabric wet curing blankets can be used for curing concrete interior or exterior slabs and pavements, as well as environmental tank walls. These blankets meet the requirements of ASTM C171, "Standard Specification for Sheet Materials for Curing Concrete." UltraCure blankets provide constant hydration, less discoloration, a more evenly cured concrete surface, and maintain a 100% relative humidity condition on the slab for 7- or 14-day curing periods. The blankets feature nonstaining, superabsorbent fibers that serve as a hydrating reservoir for the concrete as it cures. UltraCure blankets also feature a white poly backing, which provides a visual indicator that the slab remains wet.

—Sika, **http://usa.sika.com**

ER-AID Concentrate

Texas Polymer Systems' ER-AID Concentrate is an economical concentrate that can be diluted with potable water up to an average 9:1 ratio, providing an effective evaporation retardant and finishing aid for concrete flatwork. ER-AID is designed to be used as an evaporation retardant on fresh concrete surfaces forming a thin, continuous film that prevents rapid moisture loss. ER-AID is effective when concreting operations must be performed in direct sun, wind, high temperatures, or low relative humidity.

—Texas Polymer Systems, **www.texaspolymer.com**

Conkure Wet Curing Blanket

Strong Man Safety Products' Conkure™ Wet Curing Blanket is a reflective blanket designed to prevent concrete from losing moisture during the curing process. The blanket consists of highly absorbent, synthetic, needle-punched fabric. It is coated with a white reflective film, which reduces heating of the concrete surface caused by sunlight. It will not rot or mildew. Conkure Blankets are lightweight and disposable, but strong enough to be reused when cared for.

—Strong Man Safety Products, **www.strongman.com**

Two Michigan UP Companies Win Accelerate Michigan Innovation Competition

Two Michigan Upper Peninsula (UP) companies were among 10 winning finalists selected at the Accelerate Michigan Innovation Competition in Detroit, MI, November 5, 2015. QTEK LLC Founders Bowen Li and Amy Zhi won in the Life Science sector, earning $25,000 to advance Surfion, their antimicrobial additive technology. Surfion is a natural, mineral-based additive that when applied to surfaces prevents bacteria growth for the life of the product. Earning the People's Choice Award and $10,000 was Ahmeek-based Neuvokas Corporation. The company manufactures GatorBar™. This basalt fiber reinforcing bar is noncorrosive and seven times lighter than steel. For more information about the Accelerate Michigan Innovation Competition, visit **http://acceleratemichigan.org**.

Sunanda Speciality Coatings Awarded Product Innovator of the Year 2015 at India Chem Gujarat 2015

Indian construction chemical company Sunanda Speciality Coatings Pvt. Ltd. was awarded for the development of an anti-washout admixture. This award was presented by the Department of Chemicals and Petrochemicals GOI and FICCI. The concrete admixture was developed by Sunanda to be used for the underwater construction of a weir for the Srisailam Dam across the Krishna River in Andhra Pradesh, India. This admixture allows for underwater construction with less than 8% loss of cement and has the potential to improve the construction of underwater structures such as dams, bridge piers, jetties, weirs, canals, and foundations. Sunanda also won Product Innovator of the Year 2012 and 2013.

Tekla Changed Name to Trimble

Tekla as an organization has changed its name to Trimble. Tekla has been a part of Trimble since 2011. As Trimble, it will continuously develop Tekla Software for the design and construction workflow. Tekla product development and local services will continue as before.

The Institute of Concrete Technology and University of Leeds Enter into Partnership for Advanced Concrete Technology

The Institute of Concrete Technology and the University of Leeds signed a partnership agreement for jointly promoting postgraduate programs (MSc and PG Diploma) in advanced concrete technology and educating concrete technology experts who, upon graduating would be eligible to become a corporate member of the Institute. Admissions to the programs are through both academic and approved prior learning routes, fulfilling the university's policy on widening access. The programs are delivered by distance learning, a global intake of the program is expected. The university has already admitted 15 students from Australia, Europe, Oman, South Africa, and the United Kingdom to its inaugural program.

PERI Expands Production Capacities for Scaffolding Systems

PERI announced the purchase of the Silvergreen site in Günzburg, Germany. The new location will complement the main plant in Weissenhorn, Germany, as the expansion possibilities there are limited. As part of the company's successful strategy in the scaffolding sector and the resulting increase in sales volumes, PERI required additional production capacity. PERI Group's main scaffolding manufacturing facility will be based at the Günzburg 135,000 m² (145,000 ft²) site. Existing production in Weissenhorn will continue as before.

TAKTL Expands into Historic Manufacturing Plant and Announces New R&D Facility

TAKTL, an ultra-high performance concrete (UHPC) manufacturing company specializing in architectural façade panels and architectural elements, launched 5 years ago. The increasing demand for TAKTL resulted in the need to expand into a 140,000 ft² (13,000 m²) factory, and to create a 45,000 ft² (4200 m²) R&D facility. TAKTL's campus, developed in collaboration with the Regional Industrial Development Corporation, also includes plans for a new office building. Located at the former Westinghouse plant in Turtle Creek, PA, a short distance from downtown Pittsburgh, PA, the new plant includes an automated, custom-designed UHPC casting line, with seven times the current capacity, together with energy-efficient, climate-controlled curing rooms, and CNC post-processing equipment.

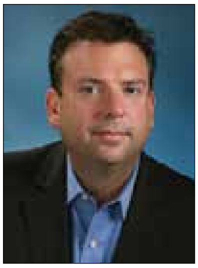
Topcon Announces Topcon Solutions Stores

Topcon Positioning Group created Topcon Solutions Stores to serve the construction, surveying, mapping, and related industries with product sales, service, and support. Topcon will continue to market its products through its independent distribution channels as well. The stores will consist of current Topcon-owned distributors Positioning Solutions Company, Bunce Positioning, Mid-Atlantic Positioning Systems, New England Positioning, and Productivity Products and Services, as well as their branch locations. The 10 Topcon Solutions stores will be located in Berlin, CT; Carol Stream, IL; Indianapolis, IN; Annapolis Junction, MD; Stow, MA; Niles, MI; St. Louis, MO; Concord, NH; Saxonburg, PA; and Waukesha, WI.

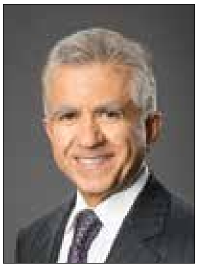
On the Move

ACI member **Todd Scharich** was named Director of Member Services of the American Society of Concrete Contractors (ASCC). Scharich has served in a part-time position with ASCC, as Decorative Concrete Specialist, since 2012. He will retain those responsibilities as well. Scharich managed a family-owned masonry construction firm in the 1990s and opened decorative concrete supply outlets serving the upper Midwest in 2000. He has been a World of Concrete speaker since 2003, in addition to speaking at numerous other events and meetings across the country. Scharich is a member of ACI Committee 310, Decorative Concrete.


Scharich


Russell


Dolata


Saiidi

Spider, a division of SafeWorks, LLC, announced **Mike Russell** as Director – Spider Market Development. He joined SafeWorks in March 2005 and has advanced through progressive leadership roles in the wind energy and rental dealership segments. Additionally, Russell serves as President of the Scaffold and Access Industry Association, the nonprofit trade association that promotes safety and training of scaffold and access through its programs.

LATICRETE promoted **Susan Dolata** to Director, Strategic Accounts Group. She has over 20 years of experience in architectural sales and account management. Most recently, she worked as Global Account Manager where she participated in architectural and national account sales for all business units and divisions of LATICRETE.

Honors and Awards

The University of Nevada, Reno, selected **M. Saiid Saiidi**, FACI, Professor, as the recipient of the 2016 Established Innovation Award. Saiidi was selected for his research in bridge earthquake engineering, investigation of advanced materials for incorporation in concrete bridges, development of patentable bridge elements in collaboration with small businesses, development of connections for accelerated bridge construction, and field implementation of innovative concepts in a demonstration bridge. Saiidi pioneered combining nickel titanium shape memory alloys (SMA) with special fiber-reinforced grout with variations that use rubber, fiber-reinforced polymers, copper-aluminum-manganese SMA, and deconstructible bridges. He is a member of various ACI committees.

ACI member **Clay Naito**, Associate Professor of structural engineering and Associate Chair of the Department of Civil and Environmental Engineering at Lehigh University, Bethlehem, PA, was named Precast/Prestressed Concrete Institute's (PCI) Distinguished Educator for 2015. He received his MS and PhD in civil engineering from the University of California Berkeley, Berkeley, CA, after receiving his BS in civil engineering at the University of Hawaii Manoa, Honolulu, HI. Naito has been a strong contributor to PCI since joining in 2003, serving on PCI's Technical Activities Council and holding officer positions on PCI's Blast Resistance and Structural Integrity Committee and a special Strand Bond Task Force. He served on a Blue Ribbon review committee for the seventh edition of the *PCI Design Handbook* and is a member of the eighth edition handbook committee. Naito has taught the design of precast/prestressed concrete structures at Lehigh University since 2007 and has advised student teams participating in the PCI Big Beam Competition since 2008. Naito is a member of various ACI committees.

Adel El-Safty, Professor of civil environmental engineering at the University of North Florida (UNF), Jacksonville, FL, was selected as PCI's Educator of the Year. This Award recognizes engineering, architecture, and/or construction technology educators who have made significant contributions to the precast/prestressed concrete industry in their early academia careers. El-Safty has been a member of PCI since 2011. He received his PhD in 1994 from North Carolina State University, Raleigh, NC. During his tenure at UNF, El-Safty was instrumental in developing courses focused on precast/prestressed concrete for the first time. He included prestressed topics into courses on reinforced concrete design, bridge engineering, and advanced mechanics of materials. In addition, he developed a course specifically focused on prestressed concrete titled CES6715-Prestressed Concrete. The PCI Foundation has also recognized the efforts of El-Safty by supporting his development of a precast/prestressed engineering design studio at UNF. He advises students participating in the PCI Big Beam Competition and mentors many more, working with graduate and undergraduate students on various concrete research projects.

Calls for

Papers

Open Topic Oral Presentation and Poster Session

Meetings: Two 2-hour oral presentation sessions titled "Open Topic Presentations" on October 25, 2016, and one poster session titled "ACI 123 Concrete Research Poster Session" on October 24, 2016, at The ACI Concrete Convention and Exposition – Fall 2016, October 23-27, 2016, in Philadelphia, PA; sponsored by ACI Committee 123, Research and Current Developments.

Solicited: Previously unpublished information from completed studies on any aspect of structural analysis or design; concrete materials science; or construction, manufacturing, use, and maintenance of concrete structures and products. The purpose of this session is to offer authors/speakers an open forum for presentation of recent technical information that does not fit into other sessions scheduled for this convention. Typical presentation time is 20 minutes for oral presentations. Posters will be displayed for the entirety of the day and authors are asked to attend the 1-hour poster session.

Requirements: 1) presentation title; 2) author/speaker name(s), title, organization, and contact information; 3) an abstract of up to 250 words and one relevant figure; and 4) preference for oral or poster presentations; although presenter preference (if indicated) will be considered, submissions will be selected for oral or poster presentation at the discretion of the moderators and committee members. Please note that abstracts exceeding 250 words will not be accepted. Duplicate abstract submissions to both Research in Progress and Open Topic Presentation sessions will not be considered by either session; please select the appropriate session for your abstract.

Deadlines: Abstracts should be submitted electronically by August 14, 2016. Authors/speakers will be notified of the review decision for acceptance by August 28, 2016.

Send to: aciotp@gmail.com.

Thermal Testing and Calorimetry Applications for Concrete QC/QA and Troubleshooting

Meeting: Technical sessions on "Thermal Testing and Calorimetry Applications for Concrete QC/QA and Troubleshooting" at The ACI Concrete Convention and Exposition – Spring 2017, March 26-30, 2017, in Detroit, MI; sponsored by ACI Committees 231, Properties of Concrete at Early Ages, and 236, Material Science of Concrete.

Solicited: The sessions will consist of presentations highlighting productive applications of thermal and calorimetry-based testing used in concrete quality control, quality assurance, troubleshooting, mixture development, and materials screening and evaluation. The use of these technologies is becoming more widespread and diverse among concrete practitioners, material suppliers, and researchers, and is now supported by a number of ASTM International standard practices and test methods, including ASTM C1753/C1753M-15, "Standard Practice for Evaluating Early Hydration of Hydraulic Cementitious Mixtures Using Thermal Measurements"; C1679-14, "Standard Practice for Measuring Hydration Kinetics of Hydraulic Cementitious Mixtures Using Isothermal Calorimetry"; C1074-11, "Standard Practice for Estimating Concrete Strength by the Maturity Method"; and C1702-15b, "Standard Test Method for Measurement of Heat of Hydration of Hydraulic Cementitious Materials Using Isothermal Conduction Calorimetry." New and innovative uses of these and related protocols will be featured, along with practice refinements, case histories, and evolving applications of interest.

Requirements: 1) presentation title; 2) author/speaker name(s), title, organization, and contact information; and 3) an abstract of up to 300 words.

Deadline: Abstracts are due by August 31, 2016.

Send to: Tim Cost, LafargeHolcim, e-mail: tim.cost@lafargeholcim.com, telephone: +1.601.955.1622.

New Innovations in Chemical Admixtures

Meeting: Technical session on "New Innovations in Chemical Admixtures" at The ACI Concrete Convention and Exposition – Spring 2017, March 26-30, 2017, in Detroit, MI; sponsored by ACI Committee 212, Chemical Admixtures.

Solicited: ACI Committee 212 is inviting papers related to the advancement of knowledge and use of chemical admixtures for the improvement of use and economy and/or durability of concrete. Papers will be chosen by an ACI Committee 212 task group prior to the Fall 2016 ACI Convention in Philadelphia, PA.

Requirements: 1) presentation title; 2) author/speaker name(s), title, organization, and contact information; and 3) an abstract of up to 300 words.

Deadlines: Abstracts are due by August 31, 2016; final papers are due by December 16, 2016.

Send to: Kari L. Yuers, Kryton International Inc., e-mail: kari@kryton.com, telephone: +1.604.324.8280.

International *fib* Symposium 2017

Meeting: Annual *fib* symposium June 12-14, 2017, in Maastricht, The Netherlands. The Dutch Concrete Association (Betonvereniging) and the Belgian Concrete Group (Belgische Betongroepering) will jointly organize the event.

Solicited: The symposium theme is "High Tech Concrete: Where Technology and Engineering Meet!" Symposium topics will include materials technology; modeling, testing, and design; special loadings; safety, reliability, and codes; existing concrete structures; durability and lifetime; sustainability; innovative building concepts; challenging projects; and historic concrete. Visit www.fibsymposium2017.com for more information.

Requirements: Abstracts should be 200 to 300 words in length, must relate to the scope of the conference, and need to be written in clear English. Authors of accepted abstracts will receive instructions on the preparation of full-length papers. All submitted abstracts and papers will be fully peer-reviewed by the International Scientific Committee. Accepted papers will be published in the conference proceedings and authors will be required to give an oral presentation at the event. Abstracts should be submitted online at http://fibsymposium2017.com/call-for-papers.

Deadline: Abstracts are due by September 1, 2016.

Contact: Organising Committee *fib* 2017 Maastricht c/o Betonvereniging, Hetty Besseling, *fib* Symposium Secretariat, e-mail: info@fibsymposium2017.com.

Ultra-High-Performance Fiber-Reinforced Concrete

Meeting: Third International Symposium on Ultra-High-Performance Fiber-Reinforced Concrete (UHPFRC), October 2-4, 2017, Montpellier, France; organized by *fib*, RILEM, and AFGC, the French Association for Civil Engineering.

Solicited: Themed "Designing and Building with UHPFRC: New Large-Scale Implementations, Recent Technical Advances, Experience, and Standards," the UHPFRC 2017 Symposium will be devoted to the presentation of recent achievements on UHPFRC applications in civil engineering and bridge structures, major infrastructure projects, marine works, offshore structures; frames, roofing, large shells, and building envelopes; building elements, functional and architectural components, and aesthetics; strengthening, retrofitting, and rehabilitation; durability (characterization, feedback, use in aggressive environments); sustainability, local resources, life-cycle analysis, and recycling; design to resist extreme conditions (fire, earthquake, blast, and impacts); implementation, in-place application, and quality control; standards, recommendations, and design codes; simplified versus innovative design methods, modeling, and reliability; and fields of innovation, new markets, and related technical demand. Visit www.afgc.asso.fr/UHPFRC2017 for more information.

Requirements: Selected papers will be presented on the basis of relevance and originality to stimulate knowledge advances and UHPFRC applications. To contribute, send a one-page abstract (300 words) to the UHPFRC 2017 secretariat. Proceedings will be published by RILEM.

Deadline: Abstracts are due by September 15, 2016.

Send to: Symposium Secretariat Nadget Berrahou-Daoud, AFGC; e-mail: afgc@enpc.fr, telephone: +33.1.44.58.24.70.

Second International Conference on Bio-Based Building Materials

Meeting: Second International Conference on Bio-based Building Materials (ICBBM2017), June 21-23, 2017, in Clermont-Ferrand, France.

Solicited: The bio-based economy, and especially the area of bio-based building materials, is one of the key drivers of innovative and sustainable development of the economy and construction industry as a whole. The conference is expected to attract academics, scientists, researchers, students, designers, policy makers, and industrialists from a variety of backgrounds, including fields of engineering, materials, sustainability, architecture, and ecological technologies. General topics to be covered include natural fibers and materials, innovative hybrid composites with natural fibers, design with natural fiber composites, mechanical performances of bio-based building materials, eco-friendly binders with low CO_2 emissions and low embedded energy, durability and performance of bio-construction materials, life-cycle assessment of bio-based building materials, construction with low-binder sprayed concrete on bio-based building materials, advances in research methodologies and bio-materials testing, green and renewable energy applications in construction, and construction materials and technologies for sustainability and energy efficiency.

Requirements: Submit abstracts via the conference website: https://sites.google.com/site/icbbm2015/home.

Deadline: Abstracts are due by September 30, 2016.

Contact: ICBBM2017, Sofiane Amziane/Mohammed Sonebi, 2015ICBBM@gmail.com.

Performance-Based Seismic Design of Concrete Buildings: State of the Practice

Meeting: Sessions on "Performance-Based Seismic Design of Concrete Buildings: State of the Practice" at The ACI Concrete Convention and Exposition – Fall 2017, October 15-19, 2017, in Anaheim, CA; sponsored by ACI Committee 374, Performance-Based Seismic Design of Concrete Buildings.

Solicited: The sessions and associated ACI Special Publication (SP) available at the ACI Convention – Fall 2017 will present the state of practice for the Performance-Based Seismic Design (PBSD) of Concrete Buildings. The

Calls for Papers: Submission Guidelines

Calls for papers should be submitted no later than 3 months prior to the deadline for abstracts. Please send meeting information, papers/presentations being solicited, abstract requirements, and deadline, along with full contact information to: Keith A. Tosolt, Managing Editor, *Concrete International*, 38800 Country Club Drive, Farmington Hills, MI 48331; e-mail: keith.tosolt@concrete.org. Visit www.callforpapers.concrete.org for more information.

Calls for Papers

SP is intended to be a reference resource for the implementation of PBSD. The authors of SP papers selected by the editorial committee will be invited to present at the ACI Convention – Fall 2017. Potential topics for consideration include: PBSD design guidelines, case studies, numerical modeling, the economics of PBSD, research needs, use of experimental data for component modeling, use of high-strength reinforcement and concrete, diaphragm design, force controlled element design, international application of PBSD, observed earthquake performance of buildings designed using PBSD, experimental research for nonlinear modeling parameters and acceptance criteria, PBSD of tall buildings, and innovative techniques of PBSD.

Requirements: 1) presentation title; 2) author/speaker name(s), title, organization, and contact information; and 3) an abstract not exceeding 300 words in length. The submitted final papers should adhere to the ACI SP style and format guidelines, available at www.concrete.org/Portals/0/Files/PDF/SPManuscriptGuidelines.pdf.

Deadlines: Abstracts are due by October 17, 2016. Authors will be notified regarding acceptance of their abstract for presentation and/or publication by November 17, 2016. Papers are due by March 1, 2017, for manuscript review. Final papers are due July 1, 2017.

Send to: Editorial Committee, PBSDAnaheim@gmail.com.

Cement and Concrete Technology Conference

Meeting: 1st International Conference on Cement and Concrete Technology 2017, November 20-22, 2017, in Muscat, Oman. The event is supported by ACI, the Concrete Society, Leeds University, the Institute of Concrete Technology, and the Royal Military Technical College in Muscat.

Solicited: The 1st International Conference on Cement and Concrete Technology 2017 will be focused on developments in cement and concrete technology and will be of interest to academics and students, manufacturers, suppliers, engineers, and consultants. Conference themes will include cement chemistry, materials (admixtures, aggregates, fibers, supplementary cementitious materials), specifications and standards, sustainability (recycling, use of waste materials), durability (chlorides, sewage), high-performance/ultra-high-performance concrete, self-compacting concrete, precast concrete, hot weather concreting, testing and assessment methods, geopolymers/low-carbon cements and aggregates, surface protection methods and materials, and case studies.

Requirements: Submit a 200-word abstract online at www.concreteconference.org.uk.

Deadlines: Abstracts are due by October 30, 2016; draft papers are due by January 31, 2017.

World of Coal Ash Conference

Meeting: The World of Coal Ash (WOCA) 2017, May 8-11, 2017, in Lexington, KY.

Solicited: Coal combustion products (CCPs) use represents an important and growing industry. CCPs include fly ash, bottom ash, flue gas desulfurization materials, boiler slag, and other materials that are finding increased application in the construction, road paving, and building trades, among many others. The 2017 WOCA is a forum to discuss the science and applications for coal ash. Suggested topics include, but are not limited to: CCPs and sustainable construction; CO_2 emissions and the role for CCPs; barriers to CCP use; CCP storage and management; international perspectives; concrete, cement, and grouts; emerging technologies; and project-specific case studies.

Requirements: Details about abstract submittal are available online at www.worldofcoalash.org/presenters/callforpapers.html. Submit both the abstract and informational presenter sheet via e-mail to wocasubmission@uky.edu.

Deadline: Abstracts are due by November 7, 2016.

Contact: Alice Marksberry, University of Kentucky, Center for Applied Energy Research, telephone: +1.859.257.0311.

The Influence of Early-Age Properties' Development on Bridge Deck and Pavement Cracking and Long-Term Durability

Meeting: Technical session on "The Influence of Early-Age Properties' Development on Bridge Deck and Pavement Cracking and Long-Term Durability" at The ACI Concrete Convention and Exposition – Fall 2017, October 15-19, 2017, in Anaheim, CA; cosponsored by ACI Committee 231, Properties of Concrete at Early Ages, and several other ACI committees.

Solicited: Presentations are invited on the causes for bridge deck and/or concrete pavement cracking and how they are related to the development of early-age properties. Topics include the effect of mixture design (including materials used and proportion of materials); the influence of construction practices; the impact of specifications; the relation between bridge deck and/or concrete pavement cracking caused by early-age properties' development and the reduction of long-term durability; early-age measurement techniques that can evaluate early-age properties that are most related to bridge deck and/or concrete pavement cracking; quality assurance practices to prevent cracking; and case studies.

Requirements: 1) presentation title; 2) author/speaker name(s), title, organization, and contact information; and 3) an abstract of up to 250 words.

Deadline: Abstracts are due by February 28, 2017.

Send to: Jussara Tanesi, SES Group and Associates, jussara.tanesi.ctr@dot.gov; and Benjamin Byard, TVA, bebyard@tva.gov.

Meetings

SEPTEMBER

8-9 - **SDC Technology Forum #40**, Salt Lake City, UT
www.concretesdc.org

12-14 - **The 8th International Conference on Concrete Under Severe Conditions-Environment & Loading**, Lecco, Italy
www.consec16.com

14-16 - **Concrete Show South East Asia 2016**, Jakarta, Indonesia
http://concreteshowseasia.com

15-18 - **ASCC Annual Conference**, Minneapolis, MN
www.ascconline.org

19-21 - **9th Rilem International Symposium on Fiber Reinforced Concrete**, Vancouver, BC, Canada
https://befib2016.ca

23-26 - **APA 50th Annual Convention**, San Diego, CA
www.archprecast.org/index.php/meetings-events

25-29 - **8th World Congress on Joints, Bearings and Seismic Systems for Concrete Structures**, Atlanta, GA
www.ijbrc.org

25-29 - **Concrete 2016 Décor Show**, San Diego, CA
www.concretedecorshow.com/2016

SEPTEMBER/OCTOBER

28-1 - **NPCA's 51st Annual Convention**, Austin, TX
http://precast.org/meetings/annual-convention

28-1 - **ASCE 2016 Convention**, Portland, OR
http://asceconvention.org

ACI Industry Events Calendar:

For more information and a listing of additional upcoming events, visit **www.concrete.org/events/eventscalendar.aspx**. To submit meeting information, e-mail Lacey Stachel, Editorial Assistant, *Concrete International*, at lacey.stachel@concrete.org.

OCTOBER

5-7 - **GREENBUILD**, Los Angeles, CA
https://greenbuildexpo.com

6-11 - **TMS 2016 Annual Meeting**, Raleigh, NC
www.masonrysociety.org/html/events/index.htm

10-12 - **2016 TCA Convention**, Denver, CO
http://tilt-up.org/events/2016-tca-convention

19-21 - **HARDSCAPE North America**, Louisville, KY
www.hardscapena.com

24-26 - **The 3rd International RILEM Conferences on Microstructure Related Durability of Cementitious Composites**, Nanjing, China
www.microdurability2016.com

26-27 - **London Build 2016**, London, The United Kingdom
www.londonbuildexpo.com

THE CONCRETE CONVENTION AND EXPOSITION: FUTURE DATES

2016 — October 23-27, Marriott Philadelphia, Philadelphia, PA

2017 — March 26-30, Detroit Marriott at the Renaissance Center, Detroit, MI

2017 — October 15-19, Disneyland Hotel, Anaheim, CA

2018 — March 25-29, Grand America & Little America, Salt Lake City, UT

For additional information, contact:
Event Services, ACI, 38800 Country Club Drive,
Farmington Hills, MI 48331
Telephone: +1.248.848.3795
E-mail: conventions@concrete.org

Chapter Reports

Alberta Chapter – ACI Members Tour the Royal Alberta Museum

Members of the Alberta Chapter – ACI toured the Royal Alberta Museum construction site, located in the downtown Arts District in Edmonton, AB, Canada. The new facility will be more than twice the size of the existing museum to better showcase the province's history, and will be more equipped to host traveling exhibits from other international museums.

Ryan Renihan and Sandra Brusnyk of DIALOG kicked off the tour by presenting the highlights of the design and construction of the building. Following this, Renihan and Brusnyk, with the help of Steve Hillier, Alberta Chapter – ACI Director, and Don Neufeld of Ledcor Design-Build (Alberta) Inc., led the group on a 2-hour on-site tour to see all of the unique features of the nearly completed building. The 35 attendees explored the progress in the lobby, theatre, and gallery areas of the building; saw the massive mechanical equipment in the basement spaces; and toured the future back-of-house laboratory and office spaces.

Members of the Alberta Chapter – ACI touring the Royal Alberta Museum

The new Royal Alberta Museum consists of cast-in-place concrete foundations and predominantly two-way spanning flat plate floors supported on concrete columns. Steel framing systems are also used for some of the longer span floors and for the roofs. There are several concrete feature elements within the building, including a massive architecturally exposed concrete spiral stair that will be the focal point of the main entrance lobby.

The project was delivered using a Design-Build process, which includes Ledcor, design-build contractor; DIALOG, consulting team; and Lundholm Associates, museum consultant. An Integrated Design and Design Assist philosophy was adopted for the project, which is a collaborative approach involving all key stakeholders, subcontractors, and consultants in the building design process from concept to completion.

Visit **www.aci-alberta.org** to learn more about the chapter.

International Highest Early Strength Self-Consolidating Concrete Competition 2016

The Kuala Lumpur Chapter – ACI (ACI-KL Chapter) in collaboration with the Institute of Infrastructure Engineering and Sustainable Management (IIESM); Universiti Teknologi MARA (UiTM); Faculty of Civil Engineering UiTM, Shah Alam; and Concrete Society of Malaysia (CSM) organized the International Highest Early Strength Self-Consolidating Concrete Competition 2016 (i-HESSCCC 2016), an annual event that has been held for nearly a decade. The event was sponsored by Platinum sponsors HUME Cement and Hume Concrete Malaysia. The Construction Industry Development Board (CIDB) Malaysia, Cement Industries of Malaysia Berhad (CIMA), ALPHA Instruments, Supplies and Services, ZACKLIM Floor Specialist, NL Scientific, and MIGHTY Shield Industries sponsored the prizes and event expenditures.

Arak Azad University, Iran, won the Highest Early Strength; Hume Concrete won second place; and third was taken by Universiti Kebangsaan Malaysia (UKM). The best presentation award was presented to Diponegoro Universiti, Indonesia.

This competition was held at the Faculty of Civil Engineering, UiTM Shah Alam, Malaysia, on April 14-15, 2016, in conjunction with International Construction Week (ICW) 2016 organized by the CIDB of Malaysia. This year, the competition was extended to the international level. Participants included 36 groups from Malaysia, five groups from Indonesia, and one group from Iran, respectively.

San Diego Chapter – ACI

Chapter provides student scholarships for the 2016-2017 academic year

The San Diego Chapter – ACI approved scholarships to be granted to local students in the coming academic year.

Candidates are selected by the Chapter's Scholarship Committee from a competitive pool of applicants. All candidates must meet the following criteria: U.S. citizen, or proof of legal status in the United States; full-time student pursuing a degree in a concrete-related field; and has demonstrated academic strength, leadership ability, and industry involvement.

The 2016-2017 Scholarship Winners include:

- Arrik Montijo, University of California, San Diego (UCSD), La Jolla, CA, was awarded $1000;
- Valeria Santiago, San Diego State University (SDSU), San Diego, CA, was awarded $500;
- Julia Bermudez, SDSU, was awarded $250; and
- Mackenzie Brown, UCSD, was awarded $250.

UCSD awarded grant from PCA Education Foundation

The University of California, San Diego received a grant on May 10, 2016, from the Portland Cement Association (PCA) Education Foundation for $35,000 to help fund their research. The project research plan is to create low-cost, highly active bimetallic, nanocrystalline catalysts for CO_2 reduction. Because CO_2 is an extremely stable molecule, additional potential beyond that thermodynamically required is needed to drive electroreduction at an appreciable rate, even when using current state-of-the-art Cu catalysts. The metal catalyst provides reaction sites for the reduction to occur and has a critical impact on the reaction pathway, determining which hydrocarbons are produced. Earth-abundant Cu is known to have an intermediate binding strength for CO relative to other metal catalyst candidates including precious metals, allowing for uniquely reduced energy barriers on Cu surfaces. To learn more, visit **www2.cement.org/pdf_files/fp16-17_uca-fenning-carbon-fuel.pdf**.

San Diego Chapter – ACI upcoming events:

- September 14, 2016, Presentation on Concrete Cracking; and
- October 17, 2016, Annual Golf Tournament.

For more information, vist **www.aci-sandiego.org** or contact Heather Caya at +1.619.579.1940.

First-place winners Arak Azad University, Iran

San Diego Chapter – ACI 2016-2017 Board

Concrete cube preparation activities at the Concrete Lab, the Faculty of Civil Engineering, UiTM

Tom Tietz, Executive Director of the California Nevada Cement Association, presenting the check to David Fenning, UCSD

Public Discussion

ACI draft standards open for public discussion that are being processed through ACI's ANSI-approved standardization procedures can be found at **www.concrete.org/discussion**.

Public Discussion and Closures

Specifications for Structural Concrete (ACI 301-16)

The ACI Technical Activities Committee (TAC) approved the draft standard subject to satisfactory committee response to TAC comments in August 2014. The committee responded adequately to TAC's comments and all balloting rules were adhered to. In September 2015, the Standards Board granted approval to release the draft standard for public discussion and to process it as an ACI standard. Public discussion was announced on September 8, 2015, and closed on October 23, 2015. The committee responded to the public discussion. TAC reviewed the closure and approved it March 2016. The Standards Board approved publication of the ACI standard April 2016.

The public discussion and the committee's response to the discussion are available on ACI's website, **www.concrete.org/discussion**.

Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings (ACI 562-16) and Commentary

The ACI Technical Activities Committee (TAC) approved the draft standard subject to satisfactory committee response to TAC comments in July 2015. The committee responded adequately to TAC's comments and all balloting rules were adhered to. In December 2015, the Standards Board granted approval to release the draft standard for public discussion and to process it as an ACI provisional standard. Public discussion was announced on January 4, 2016, and closed on February 18, 2016. The committee responded to the public discussion. TAC reviewed the closure and approved it May 2016. The Standards Board approved publication of the ACI standard as a normal standard May 2016.

The public discussion and the committee's response to the discussion are available on ACI's website, **www.concrete.org/discussion**.

Design Specification for Concrete Silos and Stacking Tubes for Storing Granular Materials (ACI 313-16) and Commentary

The ACI Technical Activities Committee (TAC) approved the draft standard subject to satisfactory committee response to TAC comments in October 2013. The committee responded adequately to TAC's comments and all balloting rules were adhered to. In December 2014, the Standards Board granted approval to release the draft standard for public discussion and to process it as an ACI standard. Public discussion was announced on January 5, 2015, and closed on February 23, 2015. The committee responded to the public discussion. TAC reviewed the closure and approved it June 2015. The Standards Board approved publication of the ACI standard in May 2016.

The public discussion and the committee's response to the discussion are available on ACI's website, **www.concrete.org/discussion**.

Sinopsis en español

Mejoras en torres de un viento más altas

Lockwood, J.P.; Chase, M.J.; y McRory, S.T., *Concrete International*, V. 38, No. 8, agosto de 2016, págs. 29-32
Recientemente, se encargó la construcción de una torre de viento con una altura récord en EE. UU. (altura del eje de 115 m [377 ft]) en Adams County, IA. Este nuevo sistema de torre está fabricado 100 % en sitio, lo que permite un diámetro casi sin restricciones de la base de la torre y la altura de la torre limitados solamente por permisos de zona y los equipos de erección. En el artículo se describe el colado en sitio del segmento de la torre, la cimentación del concreto construido en sitio y la erección prefabricada de la torre.

Efecto del curado en frío con agua sobre el concreto

Kozikowski, R.L.; Brown, H.J.; Malisch, W.R.; y Suprenant, B.A., *Concrete International*, V. 38, No. 8, agosto de 2016, págs. 33-39
El documento del ACI sobre el curado (ACI 308R-16) recomienda una diferencia máxima de temperatura de 20 °F (11 °C) entre el agua del curado y el concreto para reducir esfuerzos debidos a la gradiente de temperatura que podría provocar agrietamiento. Sin embargo, esta declaración que puede rastrearse hasta ACI 308-71, no tiene el respaldo de ningún dato ni cálculo. El artículo presenta análisis elásticos e inelásticos y analiza dos experimentos para evaluar la validez de las recomendaciones de esta diferencia de temperatura de ACI.

Trabajabilidad y tiempo del fraguado del encofrado deslizante que pavimenta las mezclas de concreto

Taylor, P.C., y Wang, X., *Concrete International*, V. 38, No. 8, agosto de 2016, págs. 41-48
En este artículo se analizan dos métodos de ensayo que tienen potencial de ayudar a la industria del pavimentado de concreto a colocar los pavimentos de mejor calidad a menor precio—el ensayo de bola de vibración Kelly (vibration Kelly ball, VKelly) y el ensayo de velocidad de pulso ultrasónico (ultrasonic pulse velocity, UPV). El ensayo VKelly parece proporcionar la información útil relacionada con la respuesta de una mezcla a la vibración. El enfoque propuesto de UPV parece prometedor para las épocas de cortado de concreto pronosticadas en el campo.

Aumento de la resistencia de concretos fabricados con cementos adicionados

Aïtcin, P.-C.; Wilson, W.; y Mindess, S., *Concrete International*, V. 38, No. 8, agosto de 2016, págs. 49-52
Los cementos adicionados (aglutinantes) contienen rellenos o materiales cementantes suplementarios, que son menos reactivos que el cemento portland y, por lo tanto, reducen resistencia a la compresión temprana. Pueden utilizarse dos enfoques para superar esta reducción de la resistencia. En este artículo se analiza uno de ellos que es puramente físico y se basa en el aumento de la densidad de compactación de las partículas del aglutinante en la pasta de cemento utilizando un reductor de agua de alto rango para reducir la relación de agua y aglutinante.

¿Qué significa "fraguado inicial"?

Lee, C.H., y Hover, K.C., *Concrete International*, V. 38, No. 8, agosto de 2016, págs. 53-59
En este artículo se proporciona una comparación de los comportamientos del endurecimiento de pastas, morteros, y concretos mediante métodos de ensayos estándares y medidas no estándares orientadas al campo. Sobre la base de los resultados de los ensayos, los autores determinaron que mientras que el ensayo ASTM C403/C403M proporciona medios útiles de rastrear el proceso continuo del endurecimiento, sus valores de umbral de fijación "inicial" y "final" no coinciden necesariamente con los tiempos en el que la colocación de concreto, consolidación u operaciones de acabado del concreto que deben realizarse.

Innovación en pulido vertical de concreto

***Concrete International*, V. 38, No. 8, agosto de 2016, págs. 62-64**
Faena House, un complejo de condominios de 18 pisos en Miami Beach, FL, comprende 40,000 ft^2 (3700 m^2) de muros pulidos de concreto estructural, construido en sitio. Hasta ahora, las áreas grandes de muros verticales de concreto fueron pulidas típicamente como piezas de concreto prefabricado vaciado en el lugar y en plantas antes de que fueran colocadas. Para este proyecto, sin embargo, un inventor diseñó y colocó máquinas automatizadas capaces de rectificar y pulir superficies verticales.

Concreto de autorecocido

Ciuperca, R.I., *Concrete International*, V. 38, No. 8, agosto de 2016, págs. 65-69
Generalmente, el encofrado del concreto no se aísla y es descimbrado lo más rápido posible. Al aislar el encofrado, sin embargo, el calor y la humedad pueden quedarse en el concreto y acelerar el proceso de hidratación. Los diferenciales térmicos y de humedad también pueden también minimizarse, al reducir deformaciones unitarias de tracción cerca de las superficies del concreto. Este efecto del encofrado aislante, llamado el proceso de autorecocido, se analiza en el artículo junto con la comparación del desempeño en campo del encofrado aislante y el encofrado convencional.

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Fiber Reinforcement and Structural Concrete

Q. *Is fiber reinforcement an acceptable substitute for conventional steel reinforcement in structural concrete building elements? Does any ACI document allow the use of fiber reinforcement to serve as the primary flexural reinforcement in structural members?*

A. ACI 318-14, Section 9.6.3.1[1] (and some previous versions), allows for the use of deformed steel fiber reinforcement to enhance the properties of concrete. In Table 9.6.3.1, this improved strength is recognized by allowing a higher threshold for concrete shear strength V_c before shear reinforcement in beams is required. There is, however, no provision allowing the use of steel fiber reinforcement as flexural reinforcement. If an engineer designs a structure using materials or methods that are not included in the Code, Section 1.10 of ACI 318-14 requires that approval is obtained from the local building official. This allows for innovations that may be outside of the current Code provisions.

Table 9.6.3.1—Cases where $A_{v,min}$ is not required if $0.5\phi V_c < V_u \leq \phi V_c$

Beam type	Conditions
Shallow depth	$h \leq 10$ in.
Integral with slab	$h \leq$ greater of $2.5t_f$ or $0.5b_w$ and $h \leq 24$ in.
Constructed with steel fiber-reinforced normalweight concrete conforming to 26.4.1.5.1(a), 26.4.2.2(d), and 26.12.5.1(a) and with $f'_c \leq 6000$ psi	$h \leq 24$ in. and $V_u \leq \phi 2\sqrt{f'_c} b_w d$
One-way joist system	In accordance with 9.8

When designing concrete beams with steel fibers per ACI 318-14, Commentary Section R9.6.3.1 also recommends corrosion protection in case of chloride exposure because of the lack of data. In addition, per Section 26.4.1.5.1(a), steel fiber reinforcement is required to be deformed, conform to ASTM A820/A820M, "Standard Specification for Steel Fibers for Fiber-Reinforced Concrete," and "have a length-to-diameter ratio of at least 50 and not exceeding 100." Accompanying Commentary Section R26.4.1.5.1(a) also cautions that: "Because data are not available on the potential for corrosion problems due to galvanic action, the use of deformed steel fibers in members reinforced with stainless-steel bars or galvanized steel bars is not recommended."

Furthermore, per Section 24.4.2.2(d), a steel fiber-reinforced concrete mixture has to conform to ASTM C1116/C1116M, "Standard Specification for Fiber-Reinforced Concrete," and contain at least 100 lb of deformed steel fibers per 1 yd^3 of concrete.

All acceptance criteria in steel fiber-reinforced concrete with steel fibers used for shear resistance are provided in Section 26.12.5.1(a).

ACI also has a report (ACI 544.6R-15[2]) on analysis, design, and construction of steel fiber-reinforced concrete elevated slabs (supported on piles or columns), which contains information on full-scale testing and certification. The report includes common practices and known limitations of the system. For example, elevated two-way slabs should include structural integrity reinforcement according to Sections 4.10 and 8.7.4.2 in ACI 318-14.

Other ACI documents on fiber-reinforced concrete include ACI 544.8R-16,[3] ACI 544.1R-96(09),[4] ACI 544.2R-89(09),[5] ACI 544.3R-08,[6] and ACI 544.4R-88(09).[7]

References

1. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 519 pp.

2. ACI Committee 544, "Report on Design and Construction of Steel Fiber-Reinforced Concrete Elevated Slabs (ACI 544.6R-15)," American Concrete Institute, Farmington Hills, MI, 2015, 38 pp.

3. ACI Committee 544, "Report on Indirect Method to Obtain Stress-Strain Response of Fiber-Reinforced Concrete (FRC) (ACI 544.8R-16)," American Concrete Institute, Farmington Hills, MI, 2016, 22 pp.

4. ACI Committee 544, "Report on Fiber Reinforced Concrete (ACI 544.1R-96), (Reapproved 2009)," American Concrete Institute, Farmington Hills, MI, 1996, 64 pp.

5. ACI Committee 544, "Measurement of Properties of Fiber Reinforced Concrete (ACI 544.2R-89), (Reapproved 2009)," American Concrete Institute, Farmington Hills, MI, 1989, 11 pp.

6. ACI Committee 544, "Guide for Specifying, Proportioning, and Production of Fiber-Reinforced Concrete (ACI 544.3R-08)," American Concrete Institute, Farmington Hills, MI, 2008, 12 pp.

7. ACI Committee 544, "Design Considerations for Steel Fiber Reinforced Concrete (ACI 544.4R-88), (Reapproved 2009)," American Concrete Institute, Farmington Hills, MI, 1988, 11 pp.

Note: Additional information on the ASTM standards discussed in this article can be found at **www.astm.org**.

Questions in this column were asked by users of ACI documents and have been answered by ACI staff or by a member or members of ACI technical committees. The answers do not represent the official position of an ACI committee. Comments should be sent to rex.donahey@concrete.org.