PCA Portland Cement Association

CONCRETE TECHNOLOGY *Today*

Aging Gracefully: Architectural Concrete Panels Turn 40 Years Old

by Jamie Farny, Program Manager, Masonry and Special Products, PCA

Figures. In 1962, newly erected panels at PCA's property near Chicago put bright new faces on concrete surfaces. The display consisted of a circular walkway in exposed aggregate concrete, and white cement concrete posts supporting two panels placed back-to-back. [IMG14306, IMG15614]

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Contents

Concrete Technology Today is available on the Internet at www.concretetechnologytoday.org

New research bulletin takes a historical look at some of the early methods used to create surface aesthetics on concrete panels and discusses the panels' durability in a long-term, natural weathering exposure.

The question of architectural concrete's durability has been answered. A new report by PCA documents performance of 60 typical architectural finishes in a natural weathering exposure. Styles range from timeless classic finishes to 1960's-era design, but the techniques used to construct the panels are thoroughly contemporary.

Surface Aesthetics

The collection of panels was built to demonstrate various techniques for creating architectural concrete finishes, such as:

- chemical retarders and sand-bedding techniques for horizontally precast exposed aggregate surfaces
- form liners, rubber matting, plastic and wood forms for a variety of textures in horizontally precast panels
- colored surfaces via powdered pigments integrally mixed into fresh concrete
- two-layer construction, often with white portland cement and special aggregates contained only in the facing mix
- tooled surfaces, including sandblasting, bushhammering, grinding and polishing, and surface-bonded sheeting
- prepacked aggregate and gap-graded aggregate for vertically cast-in-place panels

After nearly 40 years of exposure to the Chicago area climate, panels were visually inspected and power washed. Ratings were made both before and after cleaning, and the findings are noteworthy. In addition

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Aging Gracefully

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The following images depict techniques and materials used in the PCA display. Except for Panel 10, all panels shown here contain white cement for some or all of the matrix. Except for Panel 25, all panels were horizontally cast. All photos shown here are original panels as cast.

Panel 4: Polystyrene blockouts and chemical retarders allowed for surface textures, and lightweight concrete was used for the back-up. Many formlined surfaces are still done in much the same way. (IMG14225)

Panel 6: Plastic stencils and sandblasting created a swirl pattern. Stencils and sandblasting have recently been used for floors, too. (IMG14229)

to the panels, posts and walkways of the exhibit that were also cast in concrete were assessed during the display's removal, and results reported.

Durability and Long-Term Performance

Panels were rated: excellent, good, fair, or poor. Most weathered extremely well, with 93% receiving an "excellent" or "good" rating. Most surfaces were sound and their appearance relatively unchanged. Slight etching or "softening" of the sharper edges was noticeable on a few surfaces, but not severe. Though some panels looked better after cleaning, many of them exhibited very minor staining from environmental sources (dirt, grime, pollution, etc.). Other than periodically cutting back vegetation to maintain a clear view, little maintenance occurred during the four decades.

Architectural Concrete Trends Today and in the Future

After presenting a detailed description of the panels' construction, the report assesses the panels' performance after long-term exposure, then covers current innovations that are changing the industry, and looks toward the future through design practices and environmental concerns that will shape the industry for many years.

For example, one current innovation in concrete technology, self-consolidating concrete (SCC), is already having an impact on concrete construction, especially in precast construction. Several characteristics make SCC particularly interesting for use in precasting facilities. Most importantly, SCC produces a good surface finish. Construction time is shorter and production of SCC is environmentally friendly (no noise, no vibration).

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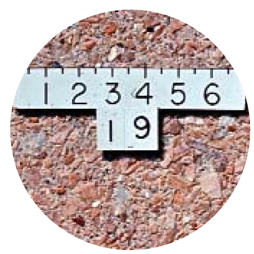
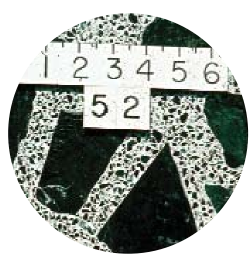
Panel 10: This panel is a forerunner of today's wide array of formliners. Sharp edges were softened over the years by minor paste erosion. (IMG14238)

Panel 15: Three aggregates in three colors—dark green, white, and pink—are combined for another exposed aggregate surface. (IMG13745)

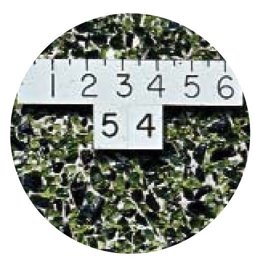


Panel 19: Pink feldspar aggregate makes a nice, somewhat sparkly pinkish-orange surface. This texture is very common for exposed aggregates. (IMG13749)

Panel 25: This panel was vertically cast by first consolidating aggregate in forms coated with surface retarders, then removing the forms, washing and brushing away surface paste, and sandblasting to deepen the texture. (IMG13754)



Panel 52: Broken pieces of marble tile were adhered to the form face and surrounded by mortar. Following aging for 60 days, the surface was ground and polished. (IMG13773)



Panel 54: Special (non-reactive) green glass used in two sizes gives a green-and-black effect. This panel also has excellent color retention. (IMG13774)

Panel 55: Special (non-reactive) orange glass and brown aggregate give a surface with excellent color retention. (IMG13775)

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Long term, there is a developing environmental awareness in the design community, called "sustainability," that has made the entire construction industry take a critical look at its practices. It is a holistic approach, helping designers and builders balance the economic, social, and environmental impacts of all actions taken to create the built environment. Concrete has an important role to play in sustainable construction.

As demonstrated by these panels' performance, concrete is a responsible choice for sustainable development because it is durable. Concrete does not rust, rot, or burn, and requires less energy and resources over time to repair or replace. It is the most widely used building material on earth and has the longest lifespan of any traditional construction material.

Summary and Conclusions

This report can serve as an idea book and a time-saving teaching guide. The authors make an excellent case for the use of concrete for exterior walls: they are aesthetically pleasing, remain durable even after decades of exposure in an often harsh North American climate, and require very little maintenance—proof that architectural concrete is cost effective over the long term. Architects, contractors, ready-mix producers, precasters, and building owners, among others, will find this information useful when designing, building, or choosing building materials and construction techniques.

Much has changed since the panels described in this report were built, yet concrete remains a versatile choice architecturally and an excellent choice environmentally. Many of the methods used to create these decorative concrete surfaces became very popular, and remain nearly unchanged today, because they are effective. The basic processes of bringing out the best appearance of concrete walls remain similar to the original methods, while improvements in the past few decades have made techniques such as exposed aggregate, form liners, and pigmented concrete even more viable today.

Reference

Panarese, W. C.; Litvin, A.; and Farny, J. A., *Performance of Architectural Panels in the PCA Outdoor Display,* RD133, Portland Cement Association, 2004, 109 pages.

Pervious Concrete Mixtures and Properites

Pervious concrete is ideally suited as a solution to stormwater management issues with added environmental benefits. The large void content designed into this specialty concrete allows water to pass through rapidly, minimizing runoff and recharging groundwater supplies. Also known as permeable concrete, porous concrete, gap-graded concrete, no-fines concrete, and enhanced porosity concrete, pervious concrete can be used in a wide range of applications, although its primary use is in pavements.

Control is the Key

Table 1 provides typical ranges of materials proportions in pervious concrete. Often, local concrete producers will be able to best determine the mix proportions for locally available materials based on trial batching and experience. ACI 211.3 provides a procedure for proportioning pervious concrete mixtures.

Figure 1. Pervious concrete uses conventional concrete materials, but the coarse aggregate is kept within a narrow grading and little to no fine aggregate is used. The paste content is also tightly controlled to provide a concrete with an open, porous structure and a high water flow capacity. Photo courtesy of CTL.

Table 1. Typical Ranges of Materials Proportions in Pervious Concrete***

Cementitious materials	270 to 415 kg/m^3 (450 to 700 lb/yd^3)
Aggregate	1190 to 1480 kg/m^3 (2000 to 2500 lb/yd^3)
Water-cement ratio (by mass)	0.27 to 0.30***
Aggregate-cement ratio (by mass)	4 to 4.5:1***
Fine-coarse aggregate ratio (by mass)	0 to 1:1****

* These proportions are given for information only.

** Chemical admixtures, particularly retarders and hydration stabilizers, are also commonly used. Use of supplementary cementitious materials, such as fly ash and slag, is common as well.

*** Higher ratios have been used, but reductions in strength and durability may result.

****Addition of fine aggregate will decrease the void content and increase strength.

Aggregates. Commonly used gradations of coarse aggregate include ASTM C 33 No. 67 (19.0 to 4.75 mm), No. 8 (9.5 to 2.36 mm), or No. 89 (9.5 to 1.18 mm). Single-sized aggregates up to 1 in. (25 mm) also have been used. ASTM D 448 also may be used for defining gradings. Larger aggregates provide a rougher concrete surface, while smaller aggregates provide a smoother surface that may be better suited to some applications, such as pedestrian walkways.

As in conventional concrete, pervious concrete requires aggregates to be close to a saturated, surface-dry (SSD) condition. It should be noted that control of water is important in pervious concrete mixtures. Water absorbed from the mixture by aggregates that are too dry (less than SSD) can lead to mixtures that do not place or compact well. Conversely, free water on aggregates (greater than SSD) will

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Pervious Concrete

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contribute to the mix water and can increase the water to cement ratio of the concrete, if not accounted for in batching.

Cementitious materials. As in traditional concreting, portland cements (ASTM C 150, C 1157) and blended cements (ASTM C 595, C 1157) may be used in pervious concrete. In addition, supplementary cementitious materials (SCMs), such as fly ash and natural pozzolans (ASTM C 618), ground-granulated blast furnace slag (ASTM C 989), and silica fume (ASTM C 1240) may be used. Testing materials through trial batching is strongly recommended so that proper proportions for the desired concrete performance (which includes setting time, rate of strength development, porosity, and permeability, among other traits) can be established.

Water. Water to cementitious materials ratios from 0.27 to 0.30 are used routinely with proper inclusion of chemical admixtures, and w/cm ratios as high as 0.40 have been used successfully. The relation between strength and water to cementitious materials ratio is not clear for pervious concrete. Unlike conventional concrete, the total paste content is less than the voids content between the aggregates. Therefore, making the paste stronger may not always lead to increased overall strength. Water content should be tightly controlled. The correct water content has been described as giving the mixture a sheen, without flowing off of the aggregate. A handful of pervious concrete formed into a ball will not crumble or lose its void structure as the paste flows into the spaces between the aggregates (Figure 2).

Admixtures. Chemical admixtures are used in pervious concrete to obtain special properties, as in conventional concrete. Because of the rapid setting time associated with pervious concrete, retarding or hydration-stabilizing admixtures are used commonly. Use of chemical admixtures should closely follow manufacturers' recommendations. Air-entraining admixtures can reduce freeze-thaw damage in pervious concrete and are used where freeze-thaw is a concern. ASTM C 494 governs chemical admixtures, and ASTM C 260 governs air-entraining admixtures.

Properties

Table 2 provides typical properties of pervious concrete mixtures. This table is intended to be a guide; particular mixtures should be trial batched to determine properties prior to use. Often, concrete producers will have experience with mixture designs based on available materials and can provide guidance. ACI Committee 522 is preparing a comprehensive document on pervious concrete.

Table 2. Engineering Properties of Pervious Concrete

Property	Typical Values
Slump	20 mm (3/4 in.)
Density (unit weight)	1600 to 2000 kg/m^3 (100 to 125 lb/ft^3)
Setting time	1 hour*
Porosity	15% to 25% by volume
Permeability (flow rate)	120 L/m^2/min to 320 L/m^2/min** (3 gal/ft^2/min to 8 gal/ft^2/min)
Compressive strength	3.5 MPa to 28 MPa (500 psi to 4000 psi)
Flexural strength	1 MPa to 3.8 MPa (150 psi to 550 psi)
Shrinkage	200 x 10^{-6}

* May be extended to as much as 2.5 hours with chemical admixtures.

** Laboratory mixtures with flow rates as high as 700 L/m^2/min (17 gal/ft^2/min) have been prepared.

References

Tennis, P. D.; Leming, M. L.; and Akers, D. J., *Pervious Concrete Pavements*, EB302, Portland Cement Association, Skokie, Illinois, and National Ready Mixed Concrete Association, Silver Spring, Maryland, 2004, 25 pages.

ACI 211.3R-02, *Standard Practice for Selecting Proportions for No-Slump Concrete*, American Concrete Institute, Farmington Hills, Michigan, 2002, 26 pages.

NRMCA, *Freeze-Thaw Resistance of Pervious Concrete*, National Ready Mixed Concrete Association, Silver Spring, Maryland, May 2004, 17 pages.

Southeast Cement Association, *Pervious Concrete Pavements*, http://www.pervious.info

Figure 2. Samples of pervious concrete with different water contents formed into a ball: (a) too little water, (b) proper amount of water, (c) too much water. [IMG15595, IMG15596, IMG15597]

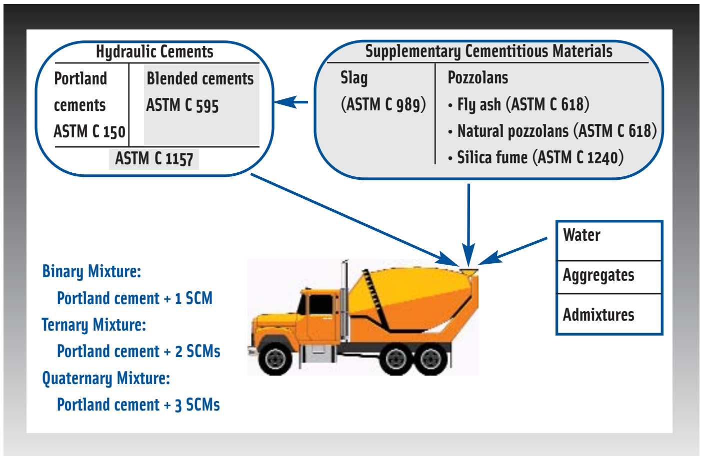

Figure 1. Supplementary cementitious materials can be added directly to concrete, through use of a blended cement, or both.

What Are Supplementary Cementitious Materials (SCMs)?

Most concrete these days is more than portland cement, aggregates, and water: according to a 1999 NRMCA survey (PCA 2000) more than half of ready-mixed concrete contains fly ash, slag, silica fume, metakaolin, or other pozzolanic materials. These materials are collectively referred to as supplementary cementitious materials (SCMs). SCMs are added to concrete for improved performance and environmental benefits, as well as for economic considerations. When properly used, SCMs can increase strength, decrease permeability, and improve resistance to alkali-silica reactivity and sulfate attack. Depending on the specific materials used, reduced heat of hydration and better workability and finishing characteristics may also be achieved.

Advantages of Blended Cements

SCMs can be included in concrete, either as an ingredient added at batching, or as a component of a blended cement (Figure 1). Primarily, SCMs are added during batching along with portland cement. This is favored by many concrete producers, as they can control the quantity of SCMs to match the concrete application. SCMs can also be added to concretes made with blended cements.

Since the benefits of SCMs arise from their physical and chemical characteristics, it might be assumed that similar performance in concrete is achieved, for example, by adding a fly ash at a ready-mixed concrete batch plant or through use of a blended cement made with fly ash. Although good concrete performance can be achieved through both techniques, blended cements provide an advantage in that they can be produced with the same quality control techniques as portland cements, including control of fineness and optimization of sulfate content. Sulfate optimization can be particularly important for some fly ashes with high aluminate contents. Although a rare occurrence, some fly ashes can throw off the sulfate balance in fresh concrete, leading to problems with workability and setting. The quality control of blended cements takes one variable out of the concrete batching process.

It is often thought that the use of SCMs in concrete—either by addition at the batch plant or by using blended cements—leads to a reduction in early-age strength. In fact, strengths for blended cements are comparable to those of portland cements. As shown in Figure 2, data from a PCA survey (Tennis 2001) indicates that early-age strengths of blended cements are comparable to Type II cements.

Applications

Blended cements can be used in virtually any concrete application including high-strength and high-performance concrete. ASTM C 595 and C 1157 provide specifications for cements for general use applications, sulfate resistance, and reduced heat of hydration. Building code provisions (such as ACI 318) limit SCMs for some applications, such as for concrete exposed to deicing materials. However, blended cements provide an option for concrete producers seeking high-quality concrete performance.

Reference

PCA, *Survey of Mineral Admixtures and Blended Cements in Ready-Mixed Concrete*, Portland Cement Association, Skokie, Illinois, October 2000, 16 pages.

Tennis, P. D., *Survey of Early-Age Strengths of Blended Cements*, Portland Cement Association, Skokie, Illinois, 2001 (unpublished).

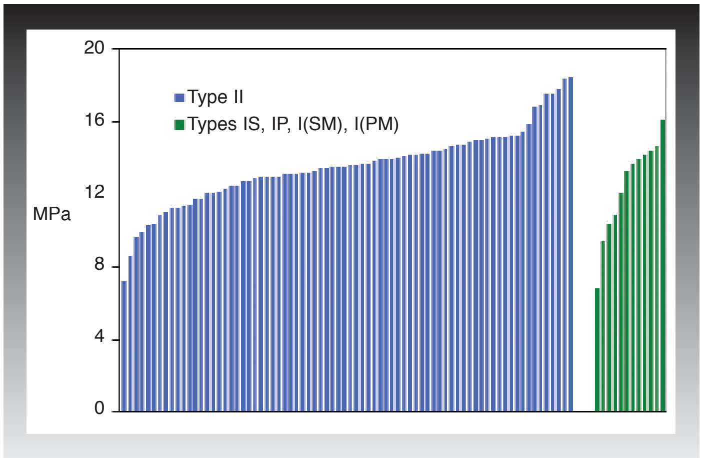

Figure 2. Generally, 1-day ASTM C 109 mortar strengths of ASTM C 595 cements are comparable to C 150 Type II cements. Later-age strengths follow this trend (Tennis 2001).

New Information Products

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The following information products are now available. To purchase them in the United States, contact the Portland Cement Association, Customer Service, 5420 Old Orchard Road, Skokie, IL 60077-1083, telephone 800.868.6733, fax 847.966.9666, or Web site ***www.cement.org***. In Canada, please direct requests to the nearest regional office of the Cement Association of Canada (Halifax, Montreal, Toronto, and Vancouver—***www.cement.ca***).

Performance of Architectural Concrete Panels in the PCA Outdoor Display, RD133

By W. C. Panarese, A. Litvin, and J. A. Farny

The information presented here makes an excellent case for the use of concrete for exterior walls: they are aesthetically pleasing, remain durable even after decades of exposure in an often harsh North American climate, and require very little maintenance. Loaded with color photos and detailed descriptions of mix designs and construction techniques. Architects, contractors, and building owners, among others, will find this information useful when designing, building, or choosing the type of construction for new properties.

Pervious Concrete Pavements, EB302

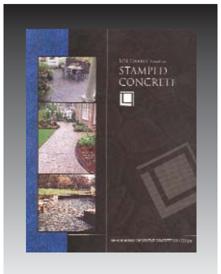
By P. D. Tennis, M. L. Leming, and D. J. Akers

Pervious concrete as a paving material has seen renewed interest due to its ability to allow water to flow through to recharge groundwater and minimize stormwater runoff. This introduction to pervious concrete pavements reviews its applications and engineering properties, including environmental benefits, structural properties, and durability. Both hydraulic and structural design of pervious concrete pavements are discussed, as well as construction techniques.

Frost Durability of Roller-Compacted Concrete Pavements, RD135

The report provides a comprehensive review on the current practices and recent developments in material selection and aggregate gradation, mixture design methods, production process, and placement techniques. Improved construction techniques and recent developments in mixture design methods have resulted in stronger more durable RCC. Data shows that as little as 1.5% of spherical air bubbles can have a beneficial influence on the frost resistance durability of RCC. Test results indicate that ASTM C 1262 appears to be a reliable method of assessing the frost durability of RCC.

Bob Harris' Guide to Stamped Concrete, LT284



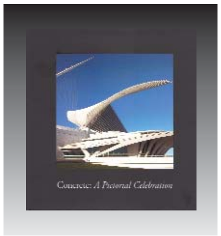
Bob Harris' Guide to Stamped Concrete is a 144-page full-color, fully illustrated, step-by-step guide that provides contractors with detailed information and practical tips to stamping concrete. The author, president of the Decorative Concrete Institute, shows contractors where to find good designs, the five methods of imparting color to stamped concrete work, placing the concrete to facilitate stamping, and the stamping process from A-Z.

Innovations in Portland Cement Manufacturing, SP400

Edited By J. I. Bhatty, F. M. Miller, and S. H. Kosmatka

This is the definitive reference for cement manufacturing. A ground-breaking work with 45 chapters of state-of-the-art information on cement manufacturing. Ten major divisions cover materials on: historical perspective on cement manufacturing, materials and fuels, pyroprocessing and kiln operation, finish milling and material handling, optimization and control, environment and energy, health and safety, analytical techniques, cement types, specifications, and properties, and future trends. This monumental work is the product of dozens of internationally renowned experts in the cement industry. *Also available on CD (CD400).*

Concrete: A Pictorial Celebration, LT285



With its wealth of photographs, this attractive book is a real eye-opener. A quick peek is sure to reveal several structures you know, whether you have traveled the world, this country, or stayed in your own hometown. Chapter after chapter speaks about one concrete superlative after another: the first, tallest, strongest, thinnest, best looking, or most efficient use of this engineered material we take for granted. And the list goes on. Learn how concrete serves the public, houses us, lets us play, works for us, and even gives us works of art. These pages celebrate the beauty and utility of concrete and are a tribute to the engineers, concrete producers, constructors, and artisans who bring the concepts to life. Copyright 2004 by the American Concrete Institute.

Education Foundation Selects 2004 Fellowship Recipients

The Portland Cement Association Education Foundation presented six graduate students from North American universities with $20,000 for research projects. The 2004 recipients are (listed by research title, student, professor, and university):

Evaluation of Strut-and-Tie Models with Actual Stress Distribution in Post-Tensioned Anchor Zones Using Nanosensor Technology
Eric Musselmann
Professor Andrea J. Schokker
The Pennsylvania State University

Development of a New Rapid Test Method for Predicting Alkali-Silica Reactivity of Concrete and Aggregate
Chang-Seon Shon
Professor Dan Zollinger
Texas A&M University

The Development of Rapid Test Methods for Measuring the Transport Properties of Concrete
David Smith
Professor Michael D. A. Thomas
University of New Brunswick

Effects of Cement Kiln Dust Chemistry and Content on Properties of Controlled Low-Strength Materials (Flowable Fill)
Rucker Williams
Professor Charles E. Pierce
University of South Carolina

Laboratory Evaluation of Thin Bonded Overlays on Roller-Compacted Concrete Pavements
Nader H. Amer
Professor Norbert Delatte
Cleveland State University

Concrete with Recycled Materials
Jean-Claude Roumain
Professor Vilem Petr
Colorado School of Mines

Figure 1. 2004 PCA Fellowship recipients and their faculty advisors after receiving their award at PCA's Joint Fall Meeting in September. (Photo by George Pfoertner Photography)

Back row (l to r): David Smith, Dan Zollinger, Vilem Petr, Norbert Delatte Front: Eric Musselmann, Charles Pierce, Rucker Williams, Chang-Seon Shon, Jean-Claude Roumain, Nader Amer, Jim Repman (Chairman, PCA Education Foundation)

2005 Research Fellowships Call for Nominations

The Portland Cement Association Education Foundation funds educational activities that will increase public knowledge regarding appropriate uses of cement and concrete. Fellowships are open to any student completing studies toward a masters or doctoral degree within Canada or the United States.

Subject areas of interest are Concrete Technology, Residential, Public Works, Masonry, Engineered Structures, and Cement Manufacturing. Innovative projects in other areas of cement and concrete technology will also be considered.

Applications must be received by **January 15, 2005**.

For details on application visit:
http://www.cement.org/2005FellowshipAnnouncement.pdf

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Education & Training

PCA's education and training group will conduct the following courses at PCA's Skokie, IL, facility. Customized and off-site courses are also available. For more information or to register, contact Julie Clausen (jclausen@cement.org).

Spring 2005 Courses

February
- **7-10** Concrete: Principles & Practices
- **14-16** Aggregates, Admixtures, & Supplementary Cementing Materials for Use in Concrete
- **14-18** Microscopy of Clinker & Cement

March
- **9-11** Troubleshooting
- **7-8** Cement & Concrete Overview
- **21-23** Mill Grinding

April
- **4-7** Kiln Process

Open Enrollment for Distance Concrete Training Course

Registration is now open for the Purdue University's Continuing Engineering Education series including a new course titled *Properties, Production, and Performance of Concrete*. The class starts on **January 10, 2005**.

Purdue CEE courses are delivered via videotape, CD/DVD, or on-demand online. Contact Rick Bohan (rbohan@cement.org) for more details.

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