Georgia Chapter ACI

NEWSLETTER

Summer 2010–Issue 6

INSDIE THIS ISSUE:

PRESIDENT'S MESSAGE

Summer wouldn't be the same without baseball, and it makes it nice when your team is doing well. As of this writing, the Braves are 2½ games up in their division. They have been leading most of the summer after a rough start. Maybe their comeback was hard work or sheer talent; maybe it was leadership from the coaches; maybe the players just wanted to give Bobby Cox a good send-off.

Leadership is more than just about winning games, and we at ACI Georgia Chapter share some similarities with our baseball team. We are a national leader among ACI chapters, largely because of the hard work and dedication of our members, both past and present. The teamwork among our members is commendable. We each sacrifice our time and talent for the good of our Chapter and our individual organizations. We strive to make those organizations better, and we try to learn from our colleagues, not content to keep the status quo. And beyond the business world, we devote our efforts to our charitable organizations, our Scout troops, our churches – all those worthwhile endeavors that make our society great.

Do you have a skill or a talent that can be used to help those around you? A big component of leadership is understanding your talents and the talents of those around you and bringing them to bear on the need at hand, whether that need is a technical challenge, a business venture, or an organizational collaboration. Look around to see how you can use your skills and talents and encourage those around you to do the same. Sometimes it is easier to coach others to use their talents than for us to use our own.

Brent Bandy, P.E., LEED® AP
Georgia Chapter ACI, President

UPCOMING EVENTS

Thurs. & Fri., September 16-17, 2010
ACI Concrete Construction Special Inspector Certification Exam Training
GC&PA Headquarters
Lake Level Conference Room
Tucker, GA
7:30 am — 5:00 pm (each day)

Thursday, September 9, 2010
ACI Field Tech Exam Training
GC&PA Headquarters
Lake Level Conf. Room
Tucker, GA
12:30 am — 4:30 pm

Saturday, September 18, 2010
ACI Field Tech Exam
TEC Services, Inc.
Lawrenceville, GA
7:30 am — 1:00 pm

Friday, September 24, 2010
GA Chapter ACI Lunch Meeting
"Polished Concrete Floors"
Speaker: David Earnest, SMS
Marriott Buckhead Hotel & Conf. Ctr.
Atlanta, GA
11:30 am Registration
12:00 pm - 1:30 pm Lunch Meeting
Information & Registration at:
www.georgiachapteraci.org

Saturday, October 2, 2010
ACI Concrete Construction Special Inspector Certification Exam
GC&PA Headquarters
Lake Level Conference Room
Tucker, GA
7:30 am — 1:00 pm

Thursday, October 7, 2010
GC&PA Headquarters
Lake Level Conf. Room
Tucker, GA
12:30 am — 4:30 pm

Saturday, October 16, 2010
ACI Field Tech Exam
Heidelberg Technology Center
Doraville, GA
7:30 am — 1:00 pm

Friday, October 22, 2010
GA Chapter ACI Lunch Meeting
MARK YOUR CALENDERS!!!!!!!!

Important Note: ACI Training & Exams are for Pre-registered Persons Only.
No walk up seating available
For Information go to:
www.cabofgeorgia.org

*** Member News ***

2010 Virgil D. Skipper Memorial Seminar

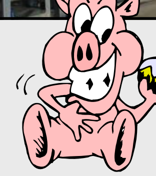
We had approximately 35 dedicated GA Chapter Members gather in Hiram, GA for the 2010 Skipper Seminar on June 16th. The half day event began at the Hiram Community Center where George Spence of Metromont, gave us a "virtual pre-cast / pre-stress plant tour"; our own Angela San Martin, P.E. followed with some specific details on things like pre-cast connections, earthquake design, thermal benefits, project types, and design considerations related to standardization, project flexibility and problem resolution.

After a coffee and doughnut break we took a walking tour of Metromont's expansive Hiram Facility where we were able to see all parts of a modern pre-cast / pre-stress plant from start to finish product. We saw specific examples of the large variety of pre-cast pieces being produced and, most interesting, was Metromont's "state of the art" recycling facility were 100% of their waste concrete is processed and reused. The walking tour concluded with a delicious BBQ Lunch provided by Rodney's Bar-B-Que.

In closing, we need to recognize four major sponsors who graciously came to our rescue by donating money to help off set some of the logistical costs of putting on this great event! ***Thank YOU!***

Big River Industries
Lafarge Cement
APAC Mid-South Aggregates
BASF Admixtures

RODNEY'S BAR-B-QUE AND CATERING



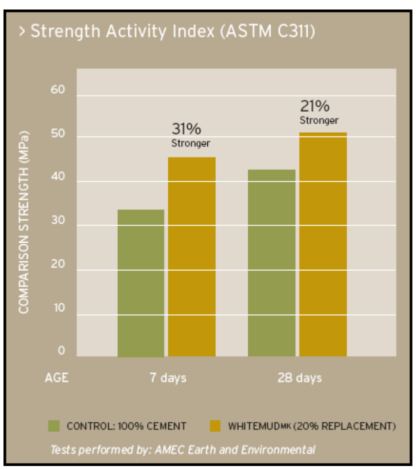
Our May Lunch Meeting

submitted by: Wayne Wilson

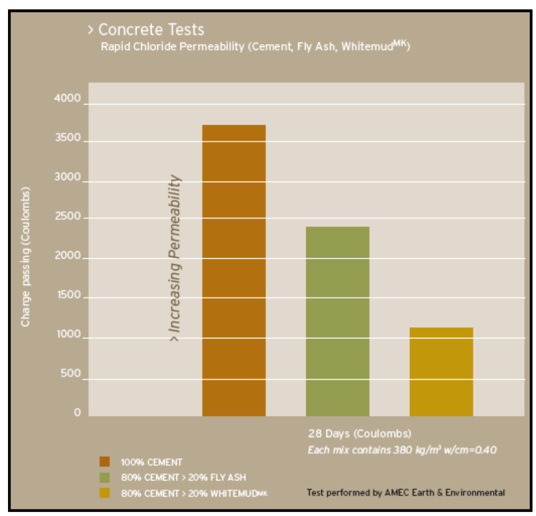
WHITEMUD RESOURCES INC.

We had a good pretty good crowd for our last lunch meeting before the summer break. Mr. Kelly Babichuk, P.E., President and Chief Operating Officer for Whitemud Resources, Inc. gave a *"What, How & Why"* presentation on High-Reactivity Metakaolin (HRM) and its beneficial use in concrete. HRM is a fine white powder derived from the clay mineral kaolinite. It is manufactured by processing and heating a naturally occurring white clay, kaolin, to 650 to 800^{o}C. Whitemud has secured the second largest known kaolin deposit in North America located in Saskatchewan, Canada.

HRM's first known use in concrete was in 1963 when it was used in Brazil's Jupia Dam. HRM is a classified as a Natural Pozzolan under ASTM C 618 and offers many advantages when used as a supplementary cementing material in concrete. Some of these advantages are:



- Increased compressive and flexural strengths.
- Greater durability which enhances sustainable attributes.
- Fewer greenhouse gas emissions in comparison to portland cement.
- Reduced permeability & efflorescence potential.
- Reduced ASR potential.
- Enhanced workability and finishing characteristics.
- Because the material is white, concrete is lighter in color which offers enhancement of integral colors and offers greater solar reflectivity.



Mr. Babichuk wrapped it up with a mention of a growing awareness of HRM by the cement, concrete, construction, oilfield and mining industries; as well as, many architects, engineers, contractors, scientists and people in the standards community. Past President, Shawn McCormick, closed the meeting by wishing everyone a safe summer and giving Mr. Babichuk a big Thank You for coming all the way down to Georgia from the great white north. Shawn finished by presenting Mr. Babichuk one of our covenanted GA Chapter ACI Mugs.

2010 GA Chapter ACI / ICRI Scholarship Fundraising Golf Tournament

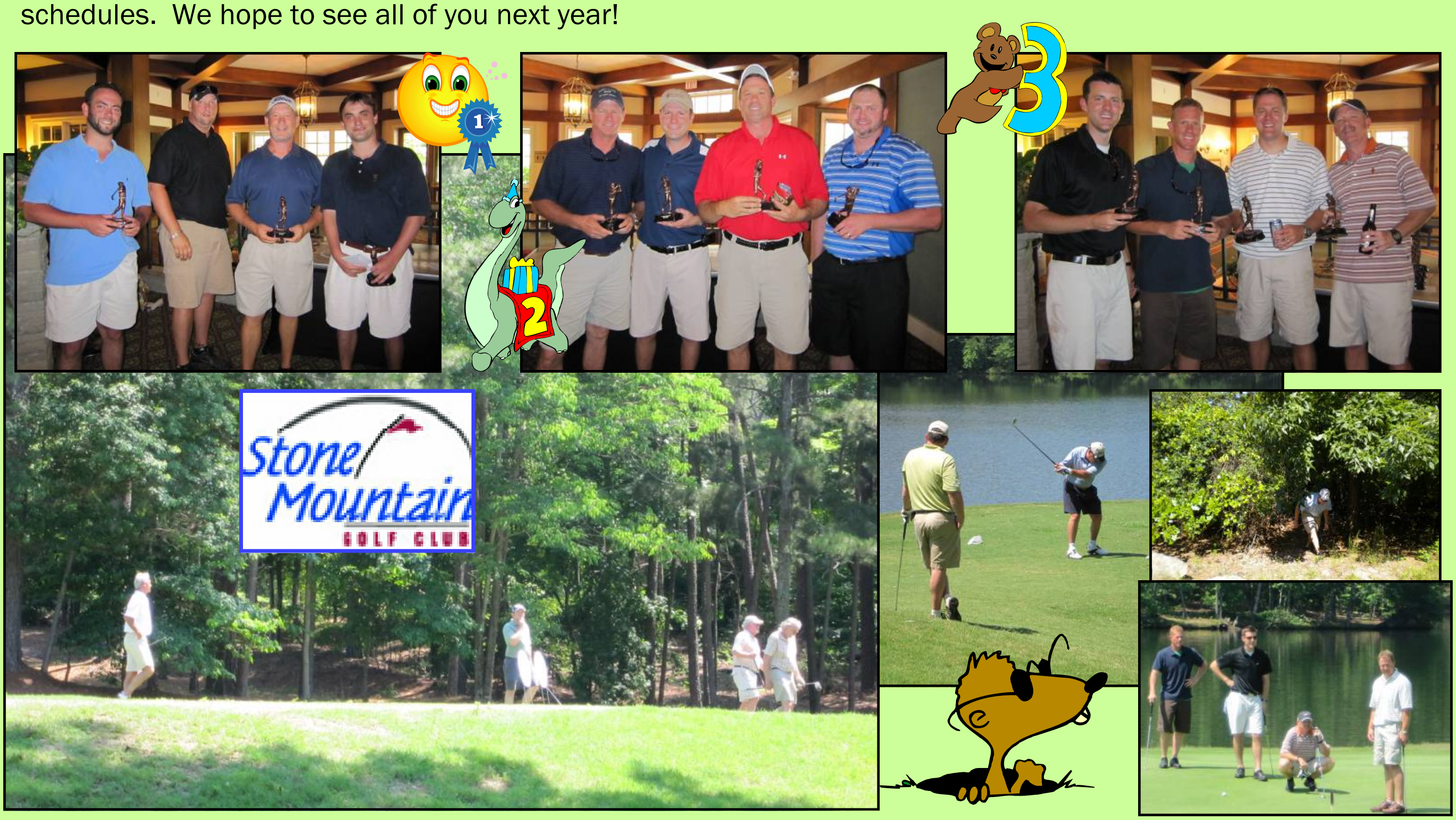
Submitted by:
Brian Wolfe & Ann Miller

On May 27, 2010 the local chapters of ACI and ICRI had their Scholarship Fundraising Golf Tournament. The outing was held on the Lakemont course of the Stone Mountain Golf Club. The tournament was very successful thanks to the fantastic weather, excited golfers and generous sponsors. We had more than 50 golfers decide to tee it up and over 40 companies sponsored holes. It was quite a generous turnout especially considering the tough economic times. All the proceeds from the tournament went directly to the scholarship funds of the local ACI and ICRI chapters.

To provide some additional incentive, trophies and prizes were awarded at the end of play for individual shots and low team scores. Brad Teal hit the shot of the day on the 8th hole (150 yard par 3) by knocking it inside 3 feet to capture closest to the pin honors. A monstrous 350 yard drive was hit by Charles Fitts to take down the long drive competition on the 18th hole. Prizes were also awarded to the top three team scores and it was as close as it gets. Two teams posted 14 under par 57's and the other team shot 58. Great playing! A scorecard playoff determined the winning team was that of Nick Chambless, Steve Mason, Zack Chambless and Lee Smith. The team of Mark Andrews, Brian Bunch, Scott Gray and Brian Wolfe finished 2nd. Our 3rd place team was that of Wes Jaillet, Ken Talley, Jason Jaillet and Brad Teal.

A special thanks also needs to go out to all the volunteers and the tournament planning team of Anne Miller, Brian Wolfe, Trip Doman, and Steven Maloof for putting together such a wonderful outing. Also we want to thank Steven Maloof for his anti-rain dance prior to the golf outing; it was disturbing to witness, but very effective.

Thanks again to all the generous hole sponsors and golfers that were able to take time away from their busy schedules. We hope to see all of you next year!



Georgia Chapter ACI

Distinguished Member Profile #8

Kenneth S. Harmon

Submitted by: Mel Galinat, F. ACI

Ken Harmon, P.E. began his career in Atlanta in 1983 after moving into the Atlanta design office of HNTB as a bridge engineer. He joined ACI National and the Atlanta Chapter for professional development opportunities. Over the next 15 years, Ken was totally involved with the chapter as it evolved into the Georgia Chapter ACI and contributed to its attainment as "the most Excellent Chapter in the world."

The friendships and networking opportunities Ken made through the Georgia Chapter have been a very important part of his life. These contacts (especially "Sam" Morris and Jeff Speck) helped him become the first Ready Mixed Concrete Promotion Engineer for the Georgia Concrete and Products Association where he served for 6-1/2 years before going to work for the Carolina Stalite Company. Ken served indefatigably as Chapter Treasurer for ten years before serving as Vice-President in 1995 and President in 1996. He served as the first Chief Engineer of the Local (Georgia) Sponsoring Group for the Field Testing Technician-Grade I Certification Program. He was also a charter member of the Georgia Chapter ACI Awards Program Committee and served as a judge for several years.

In 1998, Stalite made Ken their Sales Manager, but that required a move to North Carolina. He maintains his Chapter membership and informed us, "I really miss the Chapter and all my friends in Georgia. Whenever possible, I try to schedule my visits to Georgia around the Chapter meetings. I made two of the meetings in 2009 and it is always like 'coming home'." We miss the association with this quiet, mild-mannered guy.

Are YOU a member of ACI International?

American Concrete Institute® *Advancing concrete knowledge*

One benefit of being an ACI National Member is that you receive ACI's monthly magazine, *Concrete International*. We typically try to choose a *Concrete International* article of interest to publish here in our newsletter each month. This one article; however, represents just a very small piece of a much larger publication that is chock full of society information, news and technical information from our industry. Two, maybe lesser known, publications produced bi-monthly from ACI are the *Materials* and *Structural Journals*. These two publications contain peer reviewed Technical Papers on concrete materials and structural design research in concrete. The technical papers are generally more detailed, technical and complete than what you might see in *Concrete International* (i.e. right up all of us "techno concrete nerds" alley). To give our GA Chapter readers a little flavor of what these papers are all about I have included a recent paper in this newsletter for your enjoyment (begins on Page 6). Like what you see? Consider joining ACI National?

Wayne Wilson

GA Chapter Newsletter Editor

ACI Materials Journal, V. 107, No. 3, May-June 2010.

MS No. M-2007-403.R3 received July 9, 2009, and reviewed under Institute publication policies. Pertinent discussion including authors' closure, if any, will be published in the March-April 2011 *ACI Materials Journal* if the discussion is received by December 1, 2010.

ACI member **K. C. G. Ong** *is an Associate Professor and Deputy Head (Infrastructure and Resources) in the Department of Civil Engineering, National University of Singapore, Kent Ridge, Singapore. He received his BEng from the National University of Singapore in 1976 and his PhD from the University of Dundee, Dundee, Scotland, in 1981. He is a licensed professional engineer and a Past President of the ACI Singapore Chapter. His research interests include cementitious composites and repair and retrofit of reinforced concrete.*

Lado Riannevo Chandra *is a Graduate Research Student in the Department of Civil Engineering, National University of Singapore. He received his bachelor's degree in civil engineering from the Diponegoro University, Semarang, Central Java, Indonesia, in 2004. His research interests include early-age shrinkage of cementitious materials.*

Kyaw Myint-Lay *is a Research Fellow in the Department of Civil Engineering, National University of Singapore. He received his bachelor's degree in civil engineering from the Yangon Technological University, Yangon, Myanmar, in 2002, and his PhD from the National University of Singapore. His research interests include early-age shrinkage, image analysis, and repair of concrete.*

ACI MATERIALS JOURNAL TECHNICAL PAPER

Title no. 107-M25

Early-Age Shrinkage Strains Versus Depth of Low Water-Cement Ratio Mortar Prisms

by K. C. G. Ong, Lado Riannevo Chandra, and Kyaw Myint-Lay

*This paper presents an experimental study using an image analysis technique to monitor the variation of early-age shrinkage strains with a depth of ordinary portland cement (OPC) mortar prism specimens exposed to ambient conditions of 30 ± 0.50°C (86 ± 1°F) and 65 ± 2% RH. Starting from as early as 30 minutes after adding water to the mixture, shrinkage strains were measured at various depths from the top trowelled surfaces of OPC mortar prism specimens cast with a water-cement ratio (*w/c*) of 0.25, 0.30, or 0.35. The effect of the time zero value (that is, TZV) to initiate early-age shrinkage measurements and the gauge length used were also investigated. The results show that the absolute early-age shrinkage strains vary significantly with the depth from the top exposed surface of unsealed mortar prism specimens tested. In addition, the TZV and gauge length adopted significantly affect the absolute early-age shrinkage strain values monitored.*

Keywords: early age; image analysis; moisture loss; shrinkage.

INTRODUCTION

The shrinkage of cementitious materials is a parameter that affects the durability of concrete structures. For the past two decades, much emphasis has been placed on the early-age shrinkage of high-performance cementitious mixtures. As a low water-cementitious material ratio (*w/cm*) is common in such high-performance cementitious mixtures, an adequate and proper curing process is widely emphasized. When curing is delayed or inadequate, the loss of moisture to the environment significantly increases the magnitude of early-age shrinkage strains in such mixtures.[1] The loss of moisture starts from the exposed surface and progresses into the interior of the high-performance cementitious mixtures, depending on the inherent mixture properties and the relative humidity, temperature, and wind speed prevailing in the surrounding environment. Because moisture loss varies with the depth from the exposed surface of a cementitious material, a nonuniform distribution of shrinkage strains within the cementitious material will develop.[2] In some cases of overlays, these nonuniform shrinkage strains have been shown to be one of the major factors giving rise to surface cracking or debonding at the interface between concrete layers.[3] A review of available studies[3-6] shows that the variation of shrinkage strains within the cementitious specimens were typically monitored by assessing the internal relative humidity change[3,6] or by the direct monitoring of shrinkage strains at various depths.[4,5] In addition, it is important to note that these studies[3-6] started the shrinkage strains monitoring more than 24 hours after adding water to the mixture. Shrinkage strains monitoring using embedded strain gauges at various depths of a 150 mm (5.91 in.) thick slab that started after 7 days of moist curing was conducted by Kim and Lee.[4] It was reported that the shrinkage strain closest to the exposed surface increased rapidly, whereas in the inner portions of the concrete, the shrinkage strain changed very slowly. Another study by Al-Saleh,[5] starting after 7 days of initial curing, also reported different strain development at various depths within the cross section of standard concrete prisms. In reality, the loss of moisture due to delayed or inadequate curing can occur very early and data on the variation of shrinkage strains within the cementitious specimens during the first 24 hours after adding water to the mixture is rather scarce. An earlier study on early-age shrinkage monitoring was reported by Ong and Kyaw.[7] It reported that higher shrinkage strains were monitored using the image analysis technique when compared to those using laser measurements carried out on the same unsealed concrete prism. This was attributed to the distinct possibility of different magnitudes of shrinkage strain developing within the concrete specimen; the shrinkage strains at the top exposed surface were expected to be higher than those in the interior of the unsealed specimen. By using the image analysis method, the present study aimed to provide information on the variation of early-age shrinkage strains with depth from the top surface of mortar prism specimens when subjected to two extreme curing conditions for comparison. The variation of early-age shrinkage strains within the sealed, or adequately cured, and unsealed, or inadequately cured, ordinary portland cement (OPC) mortar prism specimens cast with a water-cement ratio (*w/c*) of 0.25, 0.30, or 0.35 was investigated. The early-age shrinkage strains were monitored well within the first 24 hours, that is, starting at 30 minutes after adding water to the mixture. Although the concept of early age may differ depending on the type of mixtures being considered, it is generally accepted that early age begins from the time during which the cementitious mixture starts to set and harden (usually within the first 24 hours after adding water to the mixture).[8,9] In this regard, the early-age shrinkage strain monitored in the present study comprises the total early-age shrinkage strain that takes place. In the case of the sealed specimens, the shrinkage strain monitored consisted primarily of autogenous shrinkage and thermal dilation, whereas in the case of the unsealed specimens, the shrinkage strain monitored consisted primarily of autogenous shrinkage, thermal dilation, and drying shrinkage (generally known as plastic shrinkage).

Another major stumbling block in quantifying and comparing the results of numerous studies on early-age shrinkage measurement is the lack of globally accepted standards. In the case of hardened cementitious specimens, the standard gauge length is well defined in ASTM C490[10] and ASTM C157/C157M.[11] The standard specimen was 75 x 75 x 285 mm (3 x 3 x 11.25 in.) for aggregates passing a 25 mm (1 in.) sieve, ...

Early-Age **continued on Page 7...**

...Early-Age continued from Page 6

... and 100 x 100 x 285 mm (4 x 4 x 11.25 in.) for aggregates passing a 50 mm (2 in.) sieve. Both had a gauge length of 250 mm (10 in.). Paradoxically, in the case of early-age shrinkage monitoring, various researchers[9,12-14] used a number of specimen sizes, shapes, and gauge lengths in their early-age shrinkage tests. Although a study by Al-Amoudi et al.[15] reported that the effect of specimen size was marginal, the effect of gauge length on early-age shrinkage strain was not comprehensively explored and quantified in the literature. A review of available studies [9,12-14] showed that the gauge length typically used the longest available gauge length, which may depend on the test setup and the specimen size. Some methods used a fixed gauge length (for example, an embedded strain gauge)[14] or, due to the nature of the instrumentation, a relatively small gauge length vis-a-vis the length of the specimen was used (for example, when fiber optic sensors or large specimens were used).[16,17] Moreover, as only one gauge length was adopted by each method, a meaningful comparison of the effects of adopting a different gauge length other than the one adopted in a particular study was not possible. In this regard, by using the image analysis technique to quantify early-age shrinkage strains, it was possible to use various gauge lengths on the same specimen and to observe the effect of gauge lengths on the early-age shrinkage strains monitored.

In relation to early-age shrinkage monitoring, a previous study by Aïtcin[18] has clearly demonstrated that careful attention should be placed on the selection of the time zero value (TZV), otherwise, the shrinkage strains monitored may substantially underestimate the actual shrinkage strains. In this regard, several researchers[9,19,20] have proposed different interpretations of the time at which shrinkage measurements should start. The Japan Concrete Institute (JCI) Technical Committee on autogenous shrinkage recommends the initial setting time obtained from penetration test as the TZV for shrinkage measurement.[21] Besides the penetration method, there are several other possible choices of the TZV determined using various methods, such as heat measurement, ultrasonic assessment, degree of cement hydration, electrical conductivity, and maturity concept.20 Nonetheless, these methods do not agree on one particular TZV to be used; however, as far as the TZV for early-age shrinkage monitoring is concerned, a distinction can be made based on whether the emphasis is via a materials or structural perspective.[9,19] In the present study, by selecting several TZVs, the effect of different TZVs on the variation of early-age shrinkage strains through the depth of the specimen was investigated.

RESEARCH SIGNIFICANCE

Using a new image analysis technique, the development of early-age shrinkage strains at different depths from the top surface of sealed and unsealed OPC mortar prism specimens cast with a *w/c* of 0.25, 0.30, or 0.35 were monitored starting as early as 30 minutes after adding water to the mixture. The development of total shrinkage strains during the period from 30 minutes after adding water to the mixture up to 24 hours later is presented and discussed with influencing factors, such as TZV and gauge lengths used. This information is useful for a better understanding of the early-age shrinkage behavior of cementitious materials cast with a low *w/c*.

EXPERIMENTAL INVESTIGATION

Materials and mixture proportion

To represent a high-performance cementitious mixture used in repair and retrofitting works, three OPC mortar mixtures were prepared with *w/c* of 0.25, 0.30, or 0.35. ASTM Type I normal OPC was used. The fine aggregate used was natural sand with a fineness modulus and specific gravity of 2.8 and 2.6, respectively, satisfying ASTM C33-9322 requirements. The proportion of fine aggregate was kept at 50% by volume. The amount of liquid from the high-range water-reducing admixture was accounted for in the mixture proportions. The mortar mixture proportions are summarized in Table 1.

Early-age shrinkage monitoring

The new image analysis technique[7] developed at the National University of Singapore was used in the present study. This technique allowed a convenient means for the monitoring of shrinkage strain as early as 30 minutes after adding water to the mixture. The image analysis technique relied on the use of high-resolution DSLR cameras (12.1 megapixels or more) to capture the movement of targets embedded in cementitious specimens. The targets were made from steel pins 75 mm (3 in.) long and 1.5 mm (0.06 in.) in diameter. These pins were topped with plastic discs 6 mm (0.24 in.) in diameter. A 4 mm (0.16 in.) square inked target was glued on the top of the plastic disc. Pairs of these 4 mm (0.16 in.) squares were used as targets for monitoring the shrinkage of the cementitious test specimen. The initial reading (that is, the first image captured) was taken approximately 30 minutes after water was added to the mixture. The subsequent images of pairs of these targets were taken at specified time intervals, for example, 5-minute intervals (within the first 0.5 to 1.5 hours), 10-minute intervals (within the 1.5 to 6 hours), and 30-minute intervals (thereafter up to 24 hours after adding water to the mixture). The series of images captured were analyzed using software that provided the coordinates of pairs of targets selected in terms of pixel values. The original distance between each pair of targets was calculated at the TZV adopted. Images of the same pair of targets at specified time intervals subsequent to this TZV were tracked and the distance between the targets was recomputed. The shrinkage strain was obtained by dividing the length change with the original length. The resolution of the image analysis technique using the present test setup was approximately "12 με.[7]

Specimen preparation and testing

As mentioned previously, two types of specimens were prepared to study the variation of early-age shrinkage strains with a depth from the top surface of the prism specimens. Sealed and unsealed specimens represent, respectively, adequately-cured and inadequately-cured OPC mortar prism specimens cast with *w/c* of 0.25, 0.30, or 0.35. Typically, four prism specimens 75 x 75 x 285 mm (3 x 3 x 11.25 in.) in size were cast for each test; three specimens for early-age shrinkage measurement and one specimen for temperature and moisture loss measurement. The steel molds were lined with 1 mm (0.0397 in.) thick polytetrafluoroethylene (PTFE) sheets to reduce friction. A lining of plastic wrap was also used between the mortar mixture and the PTFE sheets to prevent leakage of the freshly placed OPC mortar mixture. Unlike the previous study7 where the monitoring was only carried out from the top surface of the specimens, Fig. 1 shows that in the study reported herein, the shrinkage monitoring was carried out using cameras focused on two faces: the top trowelled surface of the specimens (that is, the surface shrinkage) and the side of the specimens (that is, shrinkage strains with respect to depth from the exposed/trowelled surface).

During casting, the fresh OPC mortar mixture was placed in the molds and compacted on a vibration table. The exposed top surface was trowelled smooth and the targets for shrinkage monitoring from the top surface were inserted into the freshly cast specimen. In the case of sealed specimens, the pins pierced through the plastic wrap that was placed over the top surface immediately after trowelling. Based on several preliminary tests, the effect of piercing the plastic wrap on the shrinkage strains monitored was negligible. The targets on the top surface did not settle as the pins penetrated through the full depth of the specimens. The pins were firmly bonded...

Early-Age continued on Page 8...

Table 1—Mixture proportion of mortar

Mixture	*w/c*	Aggregate volume, %	Water, kg/m³ (lb/ft³)	Cement, kg/m³ (lb/ft³)	Fine aggregate, kg/m³ (lb/ft³)	High-range water-reducing admixture: L/m³ (gal./ft³)	High-range water-reducing admixture: % by cement mass	Workability, %
M25	0.25	50	211 (13.2)	843 (52.6)	1300 (81.1)	5.28 (0.04)	0.25	140
M30	0.30	50	233 (14.5)	776 (48.4)	1300 (81.1)	2.32 (0.02)	0.12	80
M35	0.35	50	251 (15.7)	718 (44.8)	1300 (81.1)	1.26 (0.01)	0.07	90

...Early-Age continued from Page 7

… to the surrounding mortar. Although it is reasonable to expect that the bond between the pin and the freshly placed mortar might not be robust during the initial 1 to 2 hours, once the mortar mixture stiffens, the pins were expected to move along with the mortar as it hardened and shrank. This was confirmed by Ong and Kyaw[7] by comparing the shrinkage strains monitored using a laser sensor and image analysis. Both the image analysis and laser sensor registered comparable shrinkage magnitudes after the initial setting time. For studying the effect of gauge length on the shrinkage strains monitored, numerous pairs of targets were arranged so that the desired number of gauge lengths could be accommodated on the 285 mm (11.25 in.) long specimens. Figure 2 shows the nominal gauge length (that is, the distance between the selected pairs of targets). The longest nominal gauge length was 250 mm (10 in.) and the shortest was 50 mm (2 in.). The actual distance in pixel values between the selected pairs of targets was used to compute the shrinkage strains in the present study.

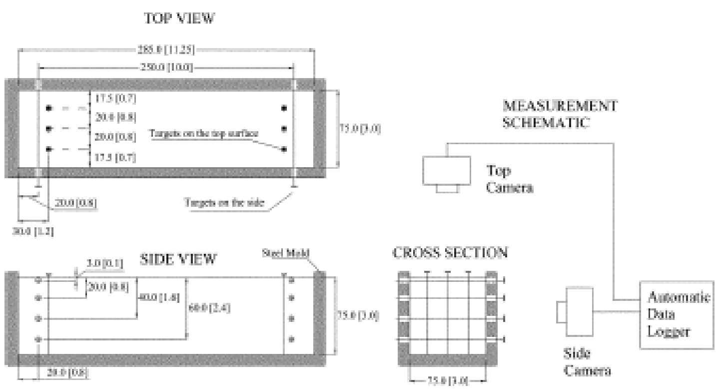


Fig. 1—Schematic diagram of shrinkage measurement. (Note: dimensions in mm [in.].)

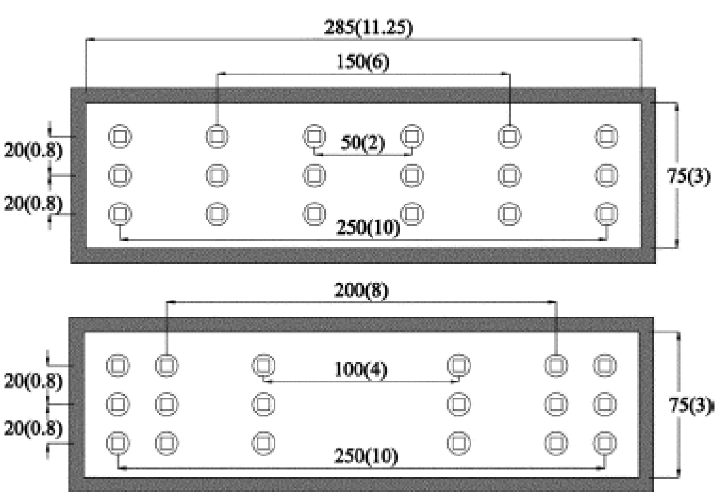


Fig. 2—Arrangement of targets on top surface for gauge length experiment. (Note: dimensions in mm [in.].)

As shown in Fig. 1, the early-age shrinkage strains on the sides of the prism specimens were monitored using pairs of targets placed at depths of 3, 20, 40, and 60 mm (0.12, 0.79, 1.57, and 2.36 in.) from the trowelled surfaces of the specimens. The targets for the shrinkage readings on the side of the specimen were positioned in the steel mold before casting. On both sides of each mold, 6 mm (0.24 in.) diameter holes were predrilled through the steel mold. Corresponding holes were also made in the PTFE sheets lining the interior faces of the steel mold. To hold the pins in position before and during casting, two semicircular rubber pieces were fitted into the 6 mm (0.24 in.) diameter holes after the pins were inserted through the plastic wrap lining the sides of the steel mold. To prevent the leakage of bleed water, a grease lubricant was applied at locations where the pins pierced the plastic wrap. The mortar mixture was placed, compacted on the vibration table, and transported to the environmental chamber with the rubber pieces left in place. These rubber pieces were removed prior to the start of early-age shrinkage monitoring. The removal of the rubber pieces did not lead to leakage of any material from the still-soft mortar due to the presence of the plastic wrap and viscous grease lubricant. The monitoring of the targets started as soon as the specimen was placed in the environmental chamber, approximately 30 minutes after adding water to the mixture and monitored continuously for 24 hours. A temperature of 30 ± 0.5°C (86 ± 0.9°F) and a relative humidity of 65 ± 2% were maintained in the environmental chamber for the entire duration of the experiment. The temperature and relative humidity were selected to simulate environmental conditions prevailing under Singapore's tropical climate.

The moisture loss with respect to time was measured during the first 24 hours after adding water to the mixture by weighing the prism specimens on a digital scale with 0.1 g (0.221×10^{-3} lb) sensitivity. The first reading was taken after casting and successive readings were taken automatically using data acquisition software. The moisture loss was computed by subtracting $w_{(i)}$ (weight at i-th hours) from $w_{(i-1)}$ (weight at (i – 1)-th hours). Simultaneously, temperature readings were monitored on the same specimen using a thermocouple via an automatic data logger with a sensitivity of 0.1°C (0.18°F). The setting time and the workability of the mortar mixture were determined via the penetration test (ASTM C403-9523) and the flow method (ASTM C1437-0124), respectively. The flow of the mortar mixture was measured just after the mixing process was completed (that is, within 10 to 15 minutes after adding water to mixture). Six 50 mm (2 in.) cubes were also cast for mortar compressive strength test according to ASTM C109/C109M-05.[25] The compressive strength test was performed on cubes at the age of 1 day and after moist curing for 28 days in the curing room at a temperature of 28 ± 0.5°C (82.4 ± 0.9°F) and a relative humidity of 98 ± 2%.

EXPERIMENTAL RESULTS AND DISCUSSION

Properties of mortar mixture, moisture loss, and temperature rise

The physical properties of the mortar mixtures can be seen in Table 2. The typical development of moisture loss in the sealed and unsealed specimens is shown in Fig. 3. In the case of the sealed mortar specimens, it may be noted that the sealing system was not perfect because there was a small amount of weight loss recorded. The weight loss at 24 hours after adding water to the mixture ranged from 0.08 to 0.12% of the total weight of the specimens. On the other hand, a typical weight loss ranging from 1.24 to 1.52% of the total weight of the specimen was registered at 24 hours after adding water to the mixture for the unsealed specimens. The present results showed that the moisture loss from the unsealed specimens increased significantly during the first few hours after adding water to the mixture. When the mortar temperature approached the peak temperature, the moisture loss started to increase more gradually.

Figure 3 also shows the temperature rise in typical sealed and unsealed specimens. The sealed specimens typically registered a higher temperature rise compared to the unsealed specimens. The higher temperature rise in the sealed specimen may be partly attributed to the insulating effect of sealing the entire specimen with plastic wrap. In the case of the unsealed specimens, the lower temperature rise may be also due to less water available for hydration as a part of mixing water was lost through evaporation. The difference in the peak temperature reached by the sealed and the unsealed specimens was typically less than 2°C (3.6°F). During the entire testing period, no cracks were visible for the range of mortar mixtures tested in the present study.

TZV for early-age shrinkage monitoring

In the present study, three TZVs were selected. The first TZV (that is, TZV_1—labeled as Point A1 and D1 in Fig. 4 and 5 for the sealed and unsealed specimens, respectively) referred to the time when the first shrinkage strains readings could be taken (that is, approximately 30 minutes after adding water to the mixture). The second TZV (that is, TZV_2—labeled as Point A2 and D2 in Fig. 4 and 5 for the sealed and unsealed specimens, ...

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Table 2—Physical properties of mortar

Mixture	Cube strength, MPa (ksi)		Initial setting time, hours	Final setting time, hours	Peak temperature time, hours		Weight loss, %	
	1 day	28 days			Sealed	Unsealed	Sealed	Unsealed
M25	56.7 (8.2)	72.4 (10.5)	4.2	5.7	8.5	9.0	0.08	1.52
M30	52.9 (7.7)	73.6 (10.7)	3.0	4.0	6.8	7.5	0.08	1.24
M35	46.0 (6.7)	60.8 (8.8)	3.2	4.5	8.4	8.6	0.12	1.46

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...respectively) referred to the initial setting time measured via the penetration resistance test. The last TZV (that is, TZV_3—labeled as Point A3 and D3 in Fig. 4 and 5 for the sealed and unsealed specimens, respectively) referred to the time when the peak temperature was monitored in the specimen. To study the effect of different TZV on the variation of early-age shrinkage strains through the depth of the specimen, the three sets of TZV (that is, A1/D1, A2/D2, and A3/D3) were used to plot the shrinkage strain-versus-time curves. Each plot assumed zero shrinkage strain at the respective TZV, neglecting any shrinkage strain prior to the respective TZV.

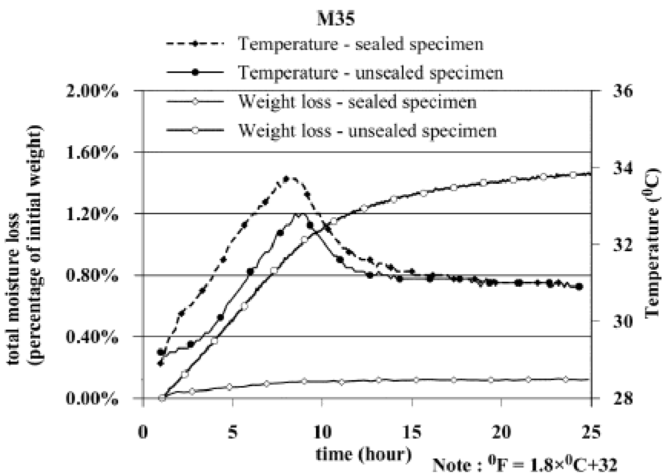

Fig. 3—Typical moisture loss and temperature rise of sealed and unsealed mortar specimens (M35 mortar mixture).

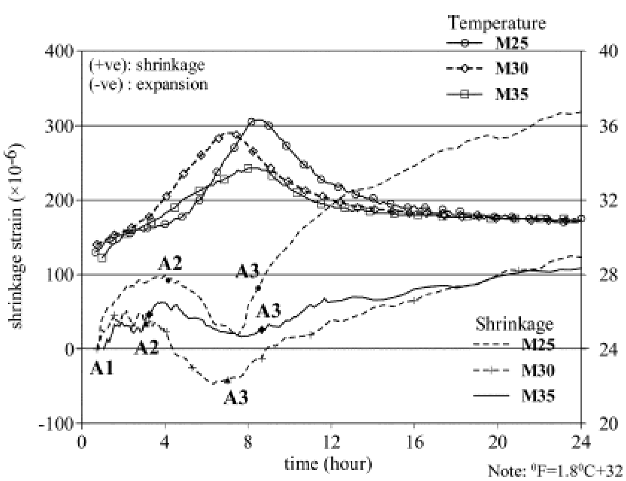

Fig. 4—Typical early-age shrinkage strain and temperature development on sealed mortar specimens starting 30 minutes after adding water to mixture.

It should be noted that the present study aims to demonstrate the effect of using different TZVs on the absolute magnitude and how early-age shrinkage strains develop within the depth of the specimen. Concerning the selection of TZV, although three TZVs were selected as described previously, other TZVs may be used as well. A review of available studies[26,27] suggests that other TZVs based on ultrasonic assessment or cement hydration occurs between TZV_1 and TZV_3. In this regard, the variations of the absolute magnitude and the development of early-age shrinkage strains within the depth of the specimen were expected to share similar characteristics to the results obtained based on TZV_1, TZV_2, and TZV_3 considered in the present study herein.

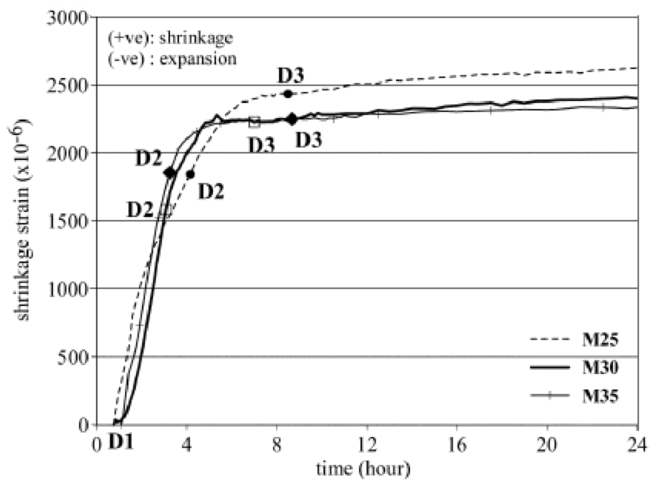

Fig. 5—Typical early-age shrinkage strain on unsealed mortar specimens starting 30 minutes after adding water to mixture.

The effect of gauge length on early-age shrinkage strains

As mentioned previously, Fig. 2 shows the arrangement of targets inserted into the top trowelled surface of the mortar specimen. The arrangement allowed shrinkage strains to be monitored based on nominal gauge lengths of 50, 100, 150, 200, or 250 mm (2, 4, 6, 8, or 10 in.). A nominal gauge length of 250 mm (10 in.) was chosen as the benchmark as per drying shrinkage in accordance to ASTM C157/C157M.[11]

Figure 6 shows a comparison between the absolute shrinkage strain values reached at 24 hours after adding water to the mixture based on the different nominal gauge lengths for the sealed mortar specimens. As mentioned previously, three TZVs were used to obtain the absolute magnitude of shrinkage strain based on five nominal gauge lengths. For the sealed mortar specimens tested, there was no significant effect of gauge length on the shrinkage strains monitored. As shown in Fig. 6(a), in the case of the M25 mortar mixture, the absolute shrinkage strain values of 330, 310, 300, 310, and 310 με were monitored using nominal gauge lengths of 50, 100,150, 200, and 250 mm (2, 4, 6, 8, and 10 in.), respectively. Using TZV2 (that is, Fig. 6(b)), the absolute shrinkage strain values of 200, 230, 220, 210, and 210 με were monitored using nominal gauge lengths of 50, 100,150, 200, and 250 mm (2, 4, 6, 8, and 10 in.), respectively. Similarly, using TZV3 (that is, Fig. 6(c)), the absolute shrinkage strain values of 290, 250, 250, 250, and 260 με were monitored using nominal gauge lengths of 50, 100,150, 200, and 250 mm (2, 4, 6, 8, and 10 in.), respectively. In the case of M30 and M35 mortar mixtures, similar trends were also observed.

Figure 7 shows a comparison between the absolute shrinkage strain values reached at 24 hours after adding water to the mixture, based on the different nominal gauge lengths for the unsealed mortar specimens. As shown in Fig. 7(a) (that is, TZV1), it can be seen that in the case of M25 ...

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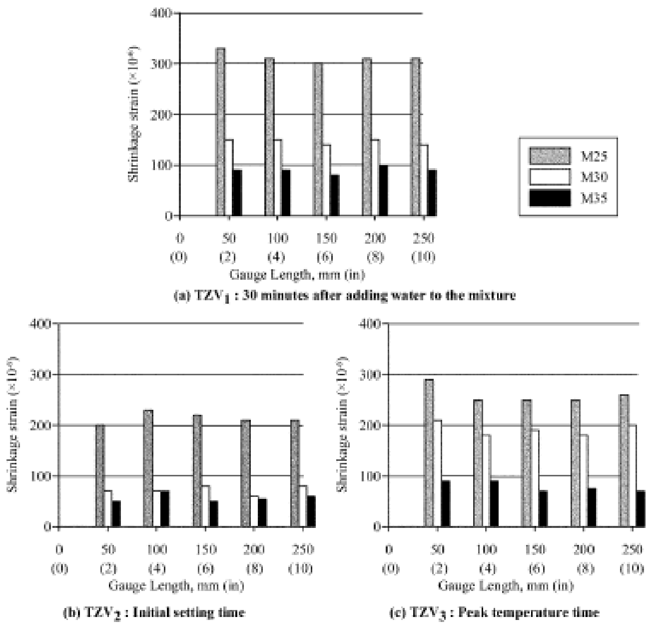

Fig. 6—Comparison between shrinkage strains monitored based on different gauge lengths on sealed mortar specimens.

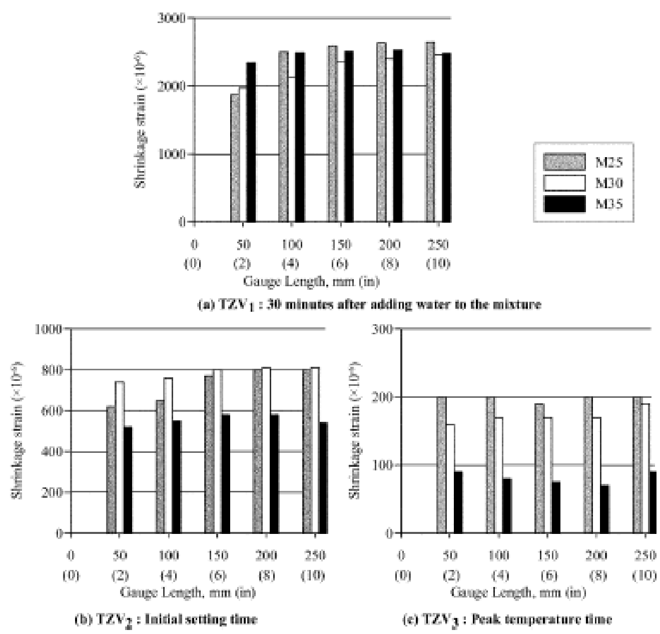

Fig. 7—Comparison between shrinkage strains monitored based on different gauge lengths on unsealed mortar specimens.

… and M30 mortar mixtures, lower absolute shrinkage strain values were registered when the nominal gauge length used was less than 150 mm (6 in.). In the case of the M35 mortar mixture, lower absolute shrinkage strain values were registered based on a gauge length of 50 mm (2 in.). Comparing the absolute shrinkage strains value monitored based on the 50 mm (2 in.) gauge length with that monitored on the benchmark gauge length (that is, 250 mm [10 in.]), a reduction of approximately 770, 490, and 140 με was observed for the M25, M30, and M35 mortar mixtures, respectively. Similarly, by using TZV2, as shown in Fig. 7(b), the absolute shrinkage strains value monitored began to decrease for all of the mortar mixtures when the gauge length used was less than 150 mm (6 in.); however, a smaller reduction in the absolute shrinkage strains value was monitored. When comparing the absolute shrinkage strains value monitored based on the 50 mm (2 in.) gauge length with that monitored on the benchmark gauge length, a reduction of approximately 180, 60, and 20 με was observed for the M25, M30, and M35 mortar mixtures, respectively. Finally, in the case of TZV3 (that is, Fig. 7(c)), no significant reduction in the absolute shrinkage strains values was monitored for the range of mortar mixtures tested. The absolute shrinkage strains value of 200, 180, and 90 με were monitored for the M25, M30, and M35 mortar mixtures, respectively, regardless of the gauge length used. Present results show that for the unsealed mortar specimens tested, the absolute shrinkage strains value monitored was affected by the gauge length and the TZV used. The absolute shrinkage strains values monitored were reduced with shorter gauge lengths coupled with a chronologically earlier TZV. In addition, the effect becomes more significant with a reduction in the *w/c*. The M25 mortar mixture registered the highest shrinkage reduction, as compared to M30 and M35 mortar mixtures; however, the effect of different gauge lengths on the absolute value of shrinkage strains monitored became negligible when a chronologically later TZV was used (for example, the time at which peak temperature is reached, that is, Point D3). Present results also showed that rather similar absolute shrinkage strains values for unsealed mortar specimens can be achieved using nominal gauge lengths of either 200 or 250 mm (8 or 10 in.). Although gauge lengths of more than 250 mm (10 in.) were not tested in the present study, shrinkage strains were expected to be similar to those based on 250 mm (10 in.) nominal gauge length.

Based on the present results for sealed specimens, a shorter gauge length may be used for monitoring early-age shrinkage strains. On the other hand, shorter gauge lengths may not be appropriate for unsealed specimens, especially if a chronologically earlier TZV is used. In this regard, it is recommended to use longer gauge lengths (that is, 200 or 250 mm [8 or 10 in.]) for typical prism specimens used for early-age shrinkage monitoring. In the present study, for further analysis of results, a nominal gauge length of 250 mm (10 in.) will be the norm used.

Early-age shrinkage of sealed and unsealed mortar specimens

Typical early-age shrinkage strains-versus-time (starting 30 minutes after adding water to the mixture) monitored from the top surface of the sealed and unsealed mortar specimens is shown in Fig. 4 and 5, respectively. No thermal corrections were made for the early-age shrinkage strains monitored as an accurate determination of the OPC mortar's coefficient of thermal expansion (CTE) was not possible using the present test setup. It is well known that as the mortar tested changed from being a suspension of the constituents of the mixtures in a liquid, to a semisolid, before finally becoming a hardened mortar within the first 24 hours after adding water to the mixture, the CTE is expected to vary considerably. As shown in Fig. 4, in the case of sealed mortar mixtures tested, as expected, the M35 mortar mixture registered the lowest temperature rise of 3.6°C (6.5°F), followed by M30 and M25 mortar mixtures with temperature rises of 6.0 and 7.2°C (10.8 and 13.0°F), respectively. Assuming an average CTE of 10 με/°C for a hardened mortar, a rough estimate of the total thermal expansion was approximately 36 to 72 με. Although the magnitude of thermal expansion was quite considerable in the case of the sealed specimens, due to the reason aforementioned, no correction was applied. In the case of unsealed mortar specimen, a similar trend was observed. The M35, M30, and M25 mortar mixtures registered temperature rises of 3.7, 5.4, and 5.8°C (6.7, 9.7, and 10.4°F), respectively. A rough estimate of thermal expansion based on the temperature rise of the unsealed specimens was approximately 36 to 58 με. This thermal expansion comprised only approximately 2 to 3% of the absolute shrinkage strains registered on the unsealed specimens at 24 hours after adding water to the mixture. Thus, the thermal expansion effect might be considered to be negligible in the case of unsealed specimens.

As shown in Fig. 4, the sealed specimens registered a contraction followed by an expansion before finally shrinking with time. The initial period of contraction could be attributed to the chemical shrinkage that occurred during the first few hours after adding water to the mixture. After the period of initial contraction, as the mortar temperature increased due to the hydration process, the sealed specimens registered an expansion. The M35 mortar mixture with the lowest temperature rise showed the smallest expansion, whereas the M30 and M25 mortar mixture showed higher expansion due to higher mortar temperature rise. The period of expansion ceased near peak temperature time (that is Point A3 in Fig. 4). From this time onward ...

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… all of the mortar mixtures registered a contraction. The contraction increased with a reduction in the *w/c*. The M25, M30, and M35 mortar mixtures showed a contraction of approximately 300, 170, and 80 με within this period, respectively.

As shown in Fig. 5, the unsealed mortar specimens registered a rapid contraction starting from 30 minutes after adding water to the mixture up to the initial setting time (that is, Point D2). After the initial setting time, the unsealed specimens shrank more gradually with time and the curve finally flattened up to the end of testing period (that is, 24 hours after adding water to the mixture). Similar to the sealed specimens, a small dip that occurred near the peak temperature time was also observed in the shrinkage strains-versus-time. This slight expansion could be attributed to the thermal expansion experienced by the unsealed mortar specimens. Reabsorption of the bleed water was negligible as no visible bleed water was noticed for the OPC mortar mixtures tested in the present study due to its low *w/c*. Comparing three unsealed mortar mixtures tested, it can be seen that the M25 mortar mixture registered the highest shrinkage strains. On the other hand, the M30 and M35 mortar mixtures showed comparable shrinkage strains up to the peak temperature time. After the peak temperature was reached, the M30 mortar mixture registered a higher rate of shrinkage strain compared to that the M35 mortar mixture. A significant difference in the shrinkage strains registered by these three mortar mixtures might be attributed to the delay in the setting of the mortar mixture. Due to its low *w/c*, the M25 mortar mixture required a significant amount of high-range water reducing admixture to achieve a similar workability. As a result, its setting was delayed. The initial setting of the M25 mortar mixture was achieved at 4.2 hours after adding water to the mixture, whereas for M30 and M35 mortar mixtures, initial setting was achieved at 3.0 and 3.2 hours after adding water to the mixture, respectively. With the longer time to reach the initial setting time, the M25 mortar mixture developed more shrinkage within this period, thus registering significantly higher shrinkage strains at the end of testing period.

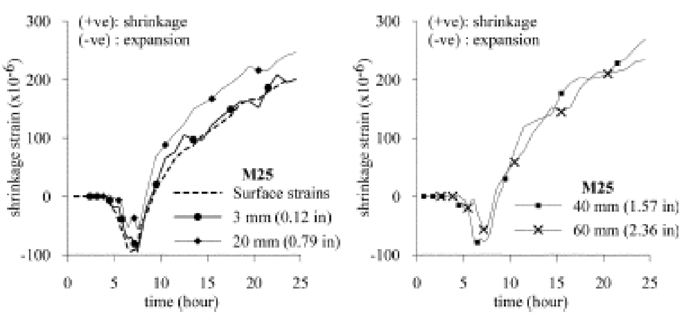

Fig. 8—Early-age shrinkage strains with respect to depth from exposed surface on M25 sealed specimens with initial setting time used as TZV.

Early-age shrinkage with respect to depth from trowelled surface

As shown previously in Fig. 1, early-age shrinkage strains were measured at various depths from the top surface of the prism specimens. The result for the sealed mortar specimens cast with *w/c* of 0.25 is shown in Fig. 8. The initial setting time (that is, Point A2) was adopted as the TZV with a nominal gauge length of 250 mm (10 in.). Early-age shrinkage strains-versus-time at various depths (that is, 3, 20, 40, and 60 mm [0.12, 0.79, 1.57, and 2.36 in.]) were plotted. The results showed that similar shrinkage strains were obtained at the various depths, implying generally uniform shrinkage across the entire cross section of the sealed specimens. As mentioned previously, the sealed mortar specimens registered an expansion caused by mortar temperature rise, starting from the initial setting time up to the time when the peak temperature was reached. From the time when the peak temperature was reached up to 24 hours after adding water to the mixture, the sealed mortar specimens started to shrink at approximately the same rate across the entire cross section, registering marginal differences with depth from the trowelled surface. Figure 9 shows the plots of shrinkage strains-versus-distance from the top surface of the sealed mortar mixtures using a different TZV. As expected, mortar mixtures cast with a lower *w/c* registered higher shrinkage strains. Starting from the initial setting time to the end of testing period (that is, 24 hours after adding water to the mixture), the M25, M30, and M35 mortar mixtures registered an average shrinkage strain absolute value of 250 με, 100 με, and 60 με, respectively. If the peak temperature time was taken as the TZV, the absolute values' shrinkage strains at 24 hours after adding water to the mixture of the M25, M30, and M35 mortar mixtures increased to 260 με, 190 με, and 90 με, respectively. In a completely sealed specimen, shrinkage was not expected to show any major differences with depth; however, some minor variations were noted in the sealed specimens tested, most probably due to a minor moisture loss from the sealed top surface and due to the resolution of the present test setup of approximately "12 με.

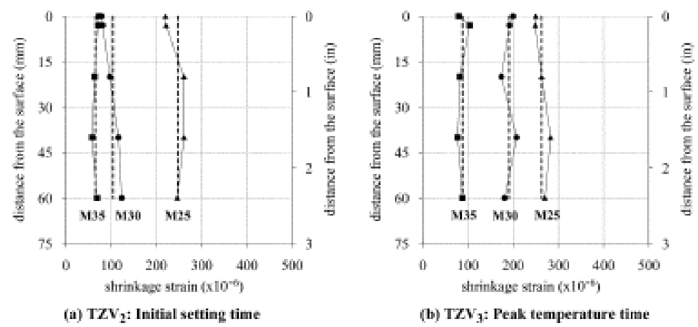

Fig. 9—Distribution of early-age shrinkage strains on side of sealed mortar specimens at 24 hours after adding water to mixture.

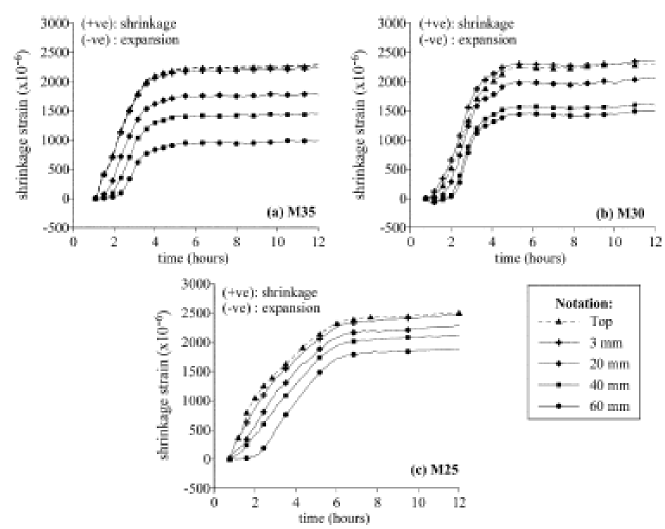

Fig. 10—Early-age shrinkage strains with respect to depth from exposed surface on unsealed specimens starting from beginning of shrinkage monitoring (that is, 30 minutes after adding water to mixture).

Figure 10 shows the development of early-age shrinkage strains in the unsealed specimens. The TZV and nominal gauge length were chosen to be the beginning of shrinkage monitoring (that is, Point D1) and 250 mm (10 in.), respectively. The results clearly showed that in the case of inadequate curing, the moisture loss affected the shrinkage strains not only near the surface layers but also throughout the depth of the unsealed mortar specimens. It can be seen that shrinkage strains near the exposed top surface started to develop earlier. The shapes of the shrinkage strain-versus time plots at different depths were similar and decreased with depth from the top surface. In the case of the M35 mortar mixture, the absolute shrinkage strain...

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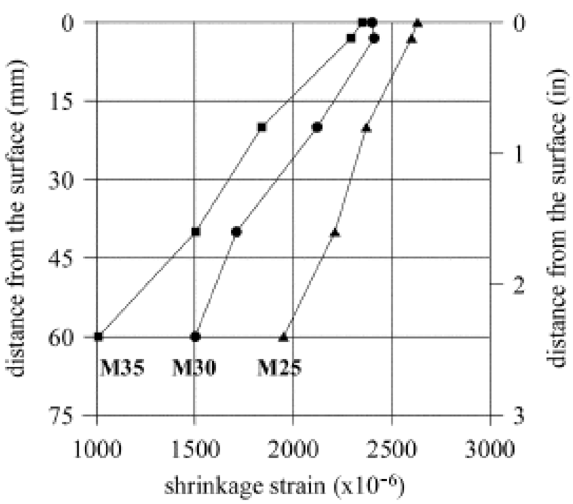
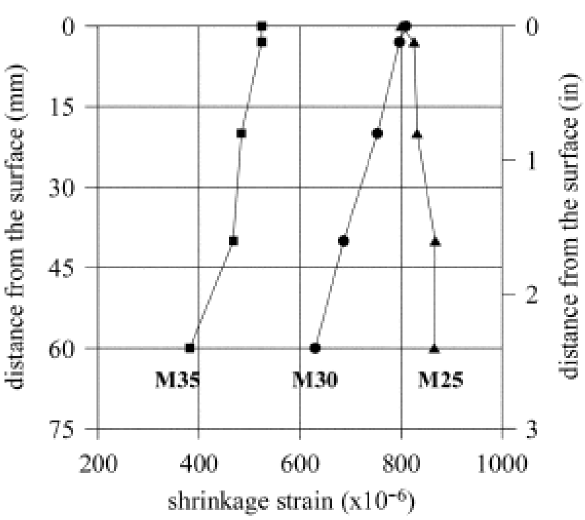
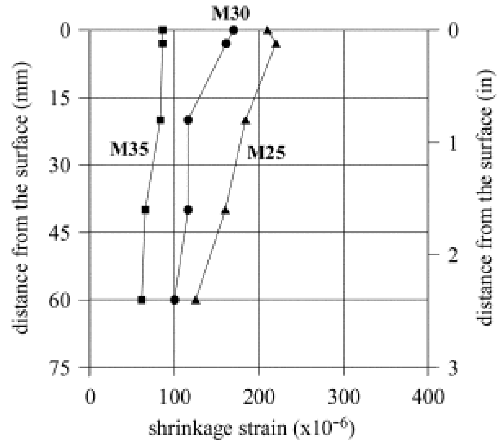
… at a depth of 3 mm (0.12 in.) reached a value of 2290 με, whereas at a depth of 60 mm (2.36 in.), the absolute shrinkage strains value only registered 1010 με at 24 hours after adding water to the mixture. Figure 11 shows the plots of shrinkage strains-versus distance from the top surface of the unsealed mortar specimens using different TZVs. The respective absolute value of shrinkage strain plotted in Fig. 11 was taken as the shrinkage strains monitored at 24 hours after adding water to the mixture. Taking the earliest TZV (that is, TZV_1), Fig. 11(a)shows that the shrinkage strains decreased rapidly with depth; thus, significantly higher shrinkage strains were monitored near the exposed surface of the unsealed specimens. At deeper depths, mortar mixtures with a lower *w/c* also registered higher absolute shrinkage strain values. The absolute shrinkage strain at a depth of 3 mm (0.12 in.) reached a value of 2290 με and 2600 με for the M35 and M25 mortar mixtures, respectively, whereas the absolute shrinkage strain at a depth of 60 mm (2.36 in.) reached a value of 1010 με and 1950 με for the M35 and M25 mortar mixtures, respectively. The higher absolute shrinkage strain values for the M25 mortar mixture could be attributed to the use of a high-range water-reducing admixture and a higher shrinkage rate in the mortar mixtures with a lower *w/c*. The use of a high-range water-reducing admixture delayed the setting time of the mortar mixtures tested. With the setting time delayed, the shrinkage induced by moisture loss would be prolonged, resulting in higher absolute shrinkage strain values. In addition, it was possible that mortar mixtures with a lower *w/c* would have finer micropores and mesopores that are responsible for the shrinkage of the mortar mixtures tested. The removal of moisture or water from these pores would generate higher capillary stresses. As a result, mortar mixtures with a lower *w/c* would register higher shrinkage strains.



(a) TZV_1: 30 minutes after adding water to the mixture



(b) TZV_2: Initial setting time



(c) TZV_3: Peak Temperature time

Fig. 11—Distribution of early-age shrinkage strains on side of unsealed mortar specimen at 24 hours after adding water to mixture.

Figures 11(b) and (c) show the plot of shrinkage strains versus- distance from the top surface of the unsealed mortar mixtures using the initial setting time and the peak temperature time as the TZV, respectively. Results showed that the absolute value of shrinkage strains decreased more gradually with a reduction in the *w/c*. An exception was noted for the M25 mortar mixture. First, in the M25 mortar mixture, the absolute shrinkage strain monitored from the top surface registered a lower value compared to that monitored at a depth of 3 mm (0.12 in). Secondly, when the initial setting time was used as the TZV (that is, Fig. 11(b)), the absolute shrinkage strain monitored near the exposed surface registered lower values compared to that monitored at deeper depths. It appears that for the M25 mixture, a discernable skin-layering effect may have taken place. As the surface layer dried out at a much faster rate than water could migrate from below the surface, the surface layer stiffened earlier, resulting in less absolute shrinkage strains at the surface (that is, 3 mm [0.12 in.] from the top). This was clearly discernable in the M25 mixture. The effect did not seem to be predominant for the M30 and M35 mixtures. Perhaps there was more moisture migration from below, replenishing the loss of moisture from the top surface.

Comparing Fig. 9(b) and 11(c), it is interesting to note that starting from the time when the peak temperature was reached up to 24 hours after adding water to the mixture, the unsealed mortar specimens registered lower absolute shrinkage strain values compared to that of the sealed specimens. The difference in the absolute shrinkage strain values between the sealed and unsealed mortar specimens increased with depth from the exposed surface. In addition, the difference also increased with a reduction in the *w/c*. While there is no exact explanation for this, it is possible that the difference in the absolute shrinkage strain values may be attributed to the difference in the hydration process present in the sealed and unsealed mortar specimens. In the unsealed mortar specimens, less water is available for the hydration process, especially within the top skin layer due to the removal of a part of mixing water through evaporation. Consequently, mortar mixtures with a lower water content were likely to be affected more. This may affect the overall shrinkage behavior of unsealed mortar specimens, resulting in lower shrinkage strains at later ages.

Comparing Fig. 9(b) and 11(c), it is interesting to note that starting from the time when the peak temperature was reached up to 24 hours after adding water to the mixture, the unsealed mortar specimens registered lower absolute shrinkage strain values compared to that of the sealed specimens. The difference in the absolute shrinkage strain values between the sealed and unsealed mortar specimens increased with depth from the exposed surface. In addition, the difference also increased with a reduction in the *w/c*. While there is no exact explanation for this, it is possible that the difference in the absolute shrinkage strain values may be attributed to the difference in the hydration process present in the sealed and unsealed mortar specimens...

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… In the unsealed mortar specimens, less water is available for the hydration process, especially within the top skin layer due to the removal of a part of mixing water through evaporation. Consequently, mortar mixtures with a lower water content were likely to be affected more. This may affect the overall shrinkage behavior of unsealed mortar specimens, resulting in lower shrinkage strains at later ages.

Based on the results of the two types of mortar specimens tested—sealed and unsealed—it is clear that moisture loss due to inadequate curing process significantly affects the shrinkage behavior of the OPC mortar mixtures tested. If the loss of moisture occurs very early, the resulting absolute value of shrinkage strains 24 hours after adding water to the mixture could reach values in excess of 2500 με, especially near the exposed trowelled surface. It is also important to note that the loss of moisture due to inadequate curing affects the absolute value of shrinkage strains throughout the depth of the prism specimen. Although the severe implications of early-age cracking have already been established, further study on the development and the variation of early-age shrinkage strains with the depth from the exposed surface is still needed, especially for high-performance cementitious mixtures with/without the addition of supplementary cementitious materials cast with low w/c.

CONCLUSION

This paper investigated the early-age shrinkage strains with respect to the depth from the surface of OPC mortar prism specimens cast with a w/c of 0.25, 0.30, or 0.35. Based on the results of the experimental study, the following conclusions could be obtained:

1. Image analysis may be used to monitor early-age shrinkage strains with respect to the depth from the trowelled surface of mortar prisms.
2. The selection of the time zero value (that is, the starting time for early-age shrinkage measurement, or TZV) affected both the absolute values and the variation with depth of early-age shrinkage strain monitored.
3. Depending on the type of specimen tested (that is, a sealed or unsealed specimen), shorter gauge lengths may not be appropriate for monitoring early-age shrinkage strains of mortar specimens. For sealed specimens, shorter gauge lengths can be used for monitoring early-age shrinkage strains without any significant difference in the absolute magnitude. On the other hand, shorter gauge lengths may not be suitable for the unsealed specimens. If too short a gauge length is used, the corresponding absolute shrinkage strain may be lower than that obtained based on a nominal gauge length of 250 mm (10 in.). The impact of gauge length on absolute shrinkage strains also depends on the TZV adopted.
4. Under an adequate curing process, the early-age shrinkage strain develops uniformly across the prism cross section. As expected, a lower w/c mortar mixture registered higher early-age shrinkage strains. Starting from the initial setting time to 24 hours after adding water to the mixture, OPC mortar mixtures cast with a w/c of 0.35 and 0.25 registered an absolute shrinkage strain value of 60 με and 250 με, respectively.
5. When inadequate or delayed curing occurs, the early-age shrinkage strains vary significantly with depth from the exposed top surface of the mortar specimens, especially when adopting a chronologically earlier TZV. In addition, an OPC mortar mixture with a lower w/c develops higher early-age shrinkage due to longer setting and how the pore structure develops. Starting from as early as 30 minutes after adding water to the mixture to the end of testing period (that is, 24 hours after adding water to the mixtures), the absolute shrinkage strains values that develop in OPC mortar specimens tested can register values in excess of 2500 με, especially near the exposed trowelled surface.

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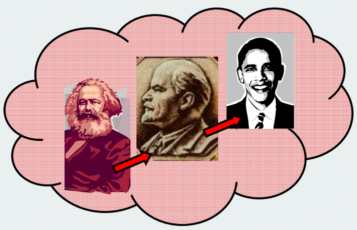

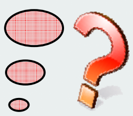

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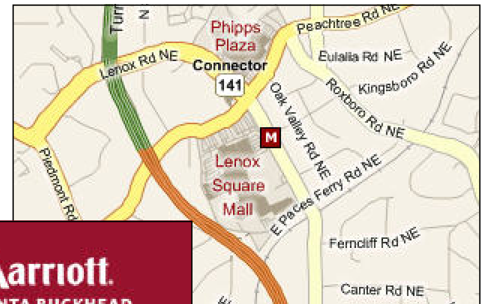
GA CHAPTER ACI
SEPTEMBER MEETING NOTICE

Date: *Friday, September 24, 2010*

Time: *Registration — 11:30 am*
Luncheon—12:00 p.m.

Location: *Marriott Atlanta Buckhead Hotel & Conference Center*
3405 Lenox Road, NE
Atlanta, Georgia 30326
Tel: 404-261-9250



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David Earnest w/ Associates at last years WOC Artistry in Concrete Demonstration.

Speaker: David Earnest
Chief Consultant w/
Substrate Management Services

SMS Substrate Management Services

David Earnest is the Chief Consultant with Substrate Management Services who provides education and consulting services for contractors on the proper procedures of polishing concrete and surface preparation along with educating end users and Architects about the different types of polished concrete and their benefits.

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Diane Dial @ ddial@mail.gcpa.org

Please RSVP by:
WEDNESDAY
September 22, 2010