INTERNAL CURING FOR THE PRESTRESS AND PRECAST CONCRETE PRODUCER

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ABSTRACT

There is a growing need today to produce concrete that is as durable and as sustainable as possible. Internal curing is an avenue that leads to the highest quality concrete available to the prestress and precast products. Thorough and maximum curing is an important procedure associated with high quality, high performance concrete. Internal curing has now been identified to cure concrete from the inside out. Lightweight aggregate sand has the ability to absorb a significant amount of water within each particle. This water is released through capillary action to the mortar fraction within the cross section of the concrete product being cast. The major benefit of internal curing is the greater impermeability such that reinforcing steel corrodes much later, if at all, increased early and complete mortar strength and its interfacial transition zone. As cement hydrates all the positive characteristics of high quality concrete are improved with the addition of an internal curing agent such as lightweight aggregate concrete sand. We will show in detail how this works for the prestress producer.

Keywords: Internal Curing**,** LWAS (lightweight aggregate sand), autogenous shrinkage, desiccation, absorption, micro-cracking.

INTRODUCTION:

There is a growing need to produce more sustainable concrete. Internal curing is a method that will achieve that end. Internal curing also affords the opportunity to reduce carbon footprints by realizing efficiencies that result in a reduction of higher carbon footprint materials.

The concept and function of internal curing is based on sound fundamental principles. We will define the process of internal curing, show the results as used in a plant environment and list an initial history as used on bridge decks in high performance concrete.

Internal curing is the process by which concrete is cured from the inside out. It is the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing water.

Projects and case studies were performed in Branford, Ct. involving pre-stressed concrete Double Tees and precast panels, in Cleveland, Ohio at the Bishop Road overpass/I-90 Spur, in conjunction with the Ohio Department of Transportation and in Lloyd, New York, at the Twaalfskill Bridge, in conjunction with the New York State Department of Transportation.

The data and history of these projects and case studies will be detailed in the course of this paper.

WHAT IS INTERNAL CURING (IC)?

Internal curing refers to the process by which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing water. (ACI-308)

For many years we have cured concrete from the outside in; internal curing cures concrete from the inside out. Internal Curing is supplied via internal reservoirs, such as absorbent lightweight aggregate, which has been pre-saturated.

Lightweight aggregate contains many small to microscopic pores. This enables the aggregate to absorb between 15% and 25% of its weight with water prior to its introduction into the concrete mix. Water within these pores desorbs as the cement/mortar paste begins its initial set. Figure 1 is a three dimensional x-ray microtomography, showing a one-day hydration view. The initial microstructure showing water filled pores that have emptied during internal curing. (4.6 mm on a side)

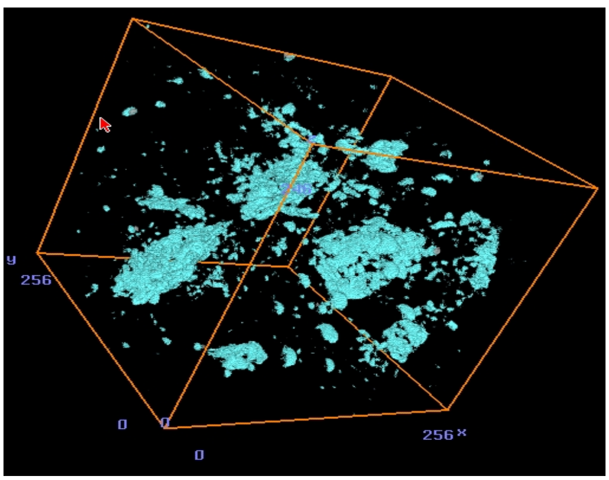

Figure 1: THREE-DIMENSIONAL X-RAY MICROTOMOGRAPHY
1-Day Hydration

WHY DO WE NEED INTERNAL CURING?

As concrete evolves from conventional design to high performance design the concrete utilizes lower water/cement ratios. Particularly in high performance concrete (HPC) it becomes increasingly difficult to provide curing water from the top surface that is adequate to satisfy the ongoing chemical shrinkage. At this time the cement paste is searching for water. Without adequate water, stresses develop that can lead to chemical shrinking, which causes autogenous shrinkage and early age cracking and micro-cracking. Internal curing can eliminate or largely reduce these detrimental conditions.

HOW DOES INTERNAL CURING WORK?

Research and development has shown that lightweight aggregate sand (LWAS) at Saturated Surface Dried (SSD) distributes the extra curing water uniformly throughout the entire concrete microstructure. Figure 2 shows a 2-Day image with water-evacuated regions (pores) overlaid on original microstructure. (4.6 mm by 4.6 mm)

It is now possible to maintain adequate saturation of the cement paste during hydration. This prevents self-desiccation, micro cracking and autogenous shrinkage. It also improves the later age characteristics of the concrete by keeping the internal relative humidity high. This increases later age strength and improves dimensional stability through reduced shrinkage and warping.

Internal curing is not a substitute for external curing. Moisture loss (after set) must still be prevented using conventional external measure e.g. (blanketing, misting, fogging and curing compound) Figure 2 shows a three-day dimensional x-ray microtomography at a two-day image with water-evacuated regions (pores) overlaid on original microstructure. (4.6 mm by 4.6 mm)

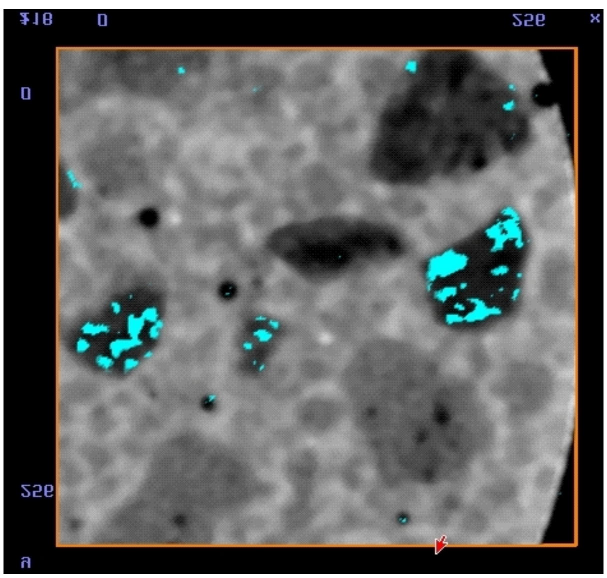

Figure 2: THREE-DIMENSIONAL X-RAY MICROTOMOGRAPHY
2-Day image with water evacuated regions

CURING PROCESS

Curing is the maintenance of a satisfactory moisture content and temperature in concrete during its early stages so that desired properties may develop. For high performance concrete, these desirable properties include: early age and later age compressive strength, flexural strength, shrinkage, cracking, creep, freeze-thaw permeability, and abrasion resistance.

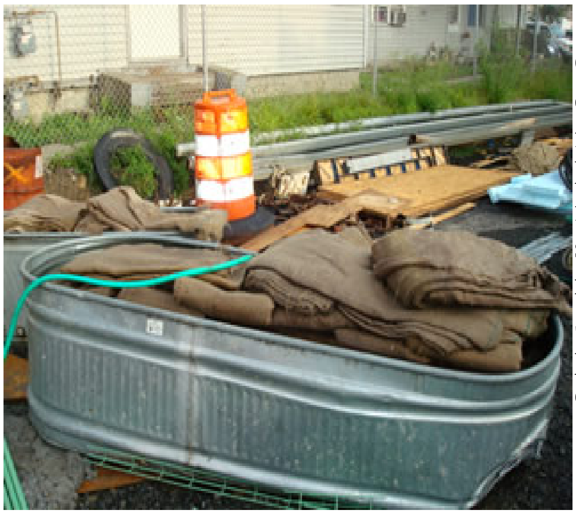

Figure 3: Burlap being soaked

Curing methods can be divided into three categories: those providing the addition of water from the outside, those that prevent or retard the loss of moisture and those that provide water from the inside. Old methods use ponding, spraying, or the use of saturated covering materials such as burlap or cotton mats. Figure 3 shows the burlap being soaked, prior to placement. Figure 4 shows the burlap being set on the newly placed concrete.

Figure: 4 Burlap being placed

Lightweight aggregate sand (LWAS) provides water from the instant the concrete is mixed and the water comes into contact with the cement. High performance concrete with Internal curing is a curing method that provides a continuous application of water to the concrete mixture. The reasons are: (1) water is so fluid, (2) the capillary action is within the hydrating cement paste are so strong and (3) the thirst (water demand) of the cement is so intense.

The internal water provides hydration of the cement where the mixing water and external water do not. The curing method should be designed into the project. With Internal Curing, the curing of concrete becomes an integral part of the production process.

EVAPORATION REDUCTION

As water evaporates near the surface of concrete, those particles of LWAS release moisture at an accelerated rate. This additional water supplements water lost through evaporation. Surface cracking due to drying stress is greatly reduced and in most cases eliminated. Figures 5 and 6 show continued wetting of the surface to reduce the evaporation rate.

Figure: 5 Evaporation reductions

Figure: 6 Evaporation reductions

PRECONDITIONING OF THE LIGHTWEIGHT AGGREGATE

It is essential that it be SSD (saturated surface dry). If it is not SSD, its beneficial results is reduced. Be sure its absorption is 10% in 30 minutes and 15% in 24 hours and SSD

PROCEDURE TO FOLLOW

Cure with water from the inside out as an adjunct to curing from the outside in. IC can more fully hydrate cement and is especially effective with high performance concrete. (HPC). Using a strong, well-graded, absorptive, lightweight aggregate sand (LWAS) with a good particle shape as a replacement of some of the natural sand in the mixture is beneficial.

MIXTURE PROPORTIONS OF THE FINE AGGREGATE IN A YARD OF CONCRETE

Table 1 illustrates the ratio of lightweight aggregate sand to lightweight sand.

Table 1: MIXTURE RATIO, LWAS AND NATURAL SAND

LWAS	NATURAL SAND
10-25%	75-90%

CASE STUDIES
BLAKESLEE PRESTRESS, BRANDORD, CONNECTICUT

Many of the prestress and precast concrete producers use slag, fly ash, silica fume or combinations of these materials. This applies to both normal strength and high performance concretes. These blended cements may have different curing requirements that often require specialized curing procedures to avoid early age cracking. Figures 7 (Double Tee) and 8 (Parking garage panel) show precast units that are produced by combining both normal strength and high performance concretes. For internal curing, a portion of natural sand was replaced with lightweight aggregate sand (LWAS).

Figure 7: Double Tee

Figure 8: Parking Garage Panel

MIX QUANTITIES AND COMPRESSIVE STRENGTH ANALYSIS

Tables 2 and 3 show the quantities ratio between sand and stone and lightweight replacement and the compressive strength analysis.

Table 2: MIX QUANTITIES WATER/CEMENT RATIO OF 0.379

	CONTROL STONE & SAND MIX #1	LIGHTWEIGHT REPLACEMENT MIX #2
Cement – Type 3	533 lbs	533 lbs
Fly Ash – Class "C"	125 lbs	125 lbs
Water	250 lbs	250 lbs
Stone – ¾"	1,801 lbs	1,801 lbs
Sand	1,151 lbs	879 lbs
LWAS	-	200 lbs
Air Admix	1 oz / 100 lbs	1 oz / 100 lbs
High Range WRA	7 oz / 100 lbs	7 oz / 100 lbs
Non-chloride Accelerator	15 oz / 100 lbs	15 oz / 100 lbs
Air Content	6.5% +/- 1.5%	6.5% +/- 1.5%
Slump	7" +/- 1 ½"	7" +/- 1 ½"

Table 3: COMPRESSIVE STRENGTH ANALYSIS
Average of (2) 4" x 8" Test Cylinders

AGE	**CONTROL MIX #1 PSI**	**LWAS MIX #2 PSI**	**IC% GAIN**
Strip (7:00am) 17 Hours total cure	**3535**	**3936**	
3 day	5037	5605	11.3
7 day	5629	6111	11.2
14 day	6007	6778	12.8
28 day	6461	7271	12.5
** 28 day **Tested at NY Lab For comparison**	6497	7451	14.6
Slump	8 ½"	7 ½"	
% Air	7.6	7.7	

All test cylinders were heat cured in Curing Boxes controlled by actual product concrete temperature

	114.9º F Panel	117.3 º F Panel
	116.9 º F C/Box	120.6 º F C/Box

Table 4 shows the freezing and thawing test results of concrete using a test method of NYSDOT 502-3P.

Table 4: RESULTS - BLAKESLEE CASE STUDY
FREEZING AND THAWING TEST OF CONCRETE
TEST METHOD: NYSDOT 502-39

The specimen type was a 4 x 8 inch cylinder, with a test solution of 3% NaCI (salt) tap water. There was full immersion during the freeze and thawing. The samples were cured for 28 days after casting, and then immersed in salt solution for 48 hours prior to starting the first freeze. The temperature ranged from frozen at 10º F, 16 hours to thawed at 70º F, 8 hours. There were 25 cycles total.

Lab Number	Percent Loss after 25 Cycles
08-0123A-1	0.3
08-0123A-2	0.3
Average	0.3

Damage consisted of slight to moderate scaling of the surface.

Table 5, shows the Freeze-Thaw resistance test results from Universal Construction Testing, Ltd., in compliance with ASTM C666-03, which is the Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing – Procedure A.

Table 5: TEST RESULTS OF ASTM C 666 - PROCEDURE A

Sample Number	Cycles	Mass Change, %	Length Change, %	Relative Dynamic Modulus %
08-0124 B1	300	-0.20	0.016	100
08-0124 B2	300	-0.10	0.012	100
08-0124 B3	300	-0.10	0.018	100

Tables 6 & 7 illustrate the Universal Construction Freeze-Thaw Testing Project # 08047 in relation to mass change percentage and length change percentage.

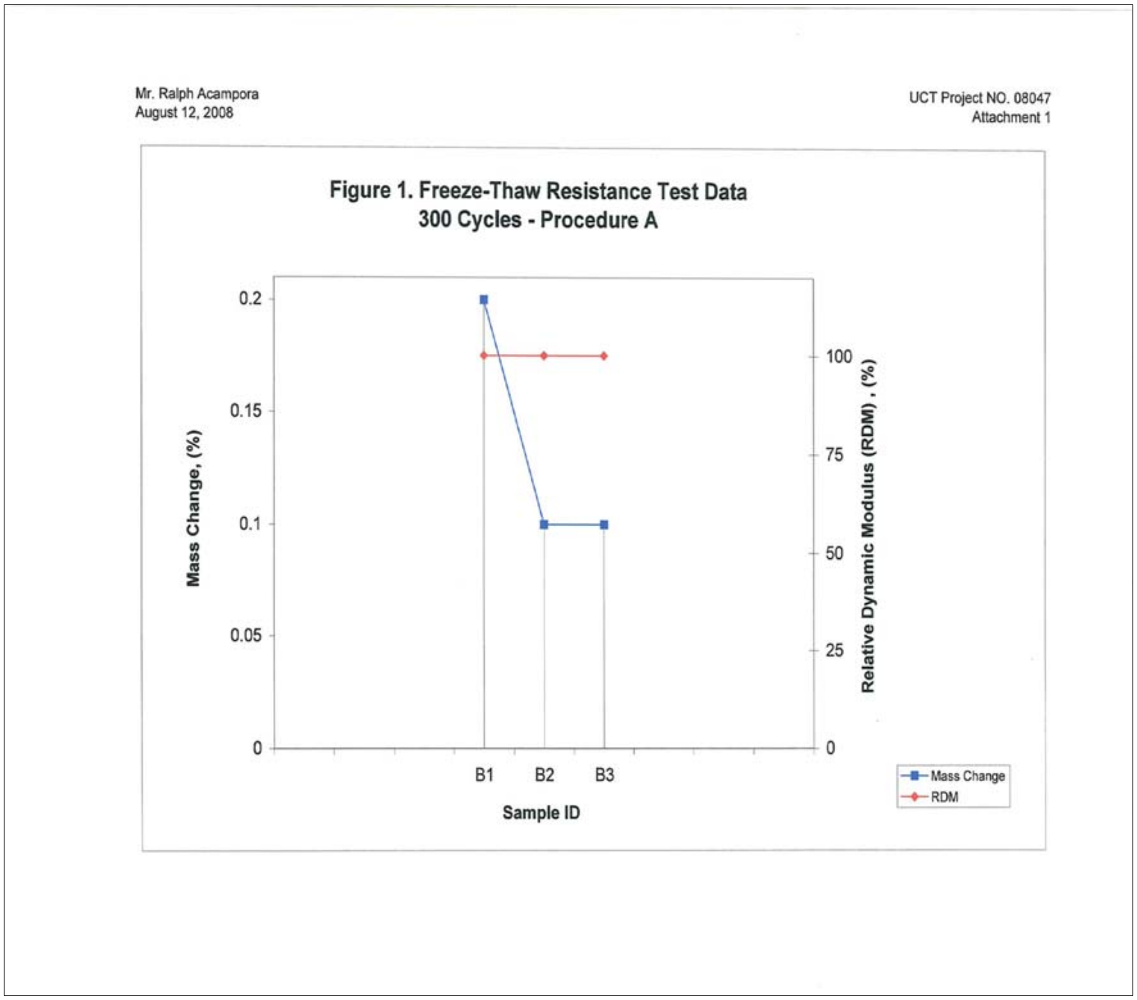

Table 6: UCT Test #08047
Freeze-Thaw – Mass Change

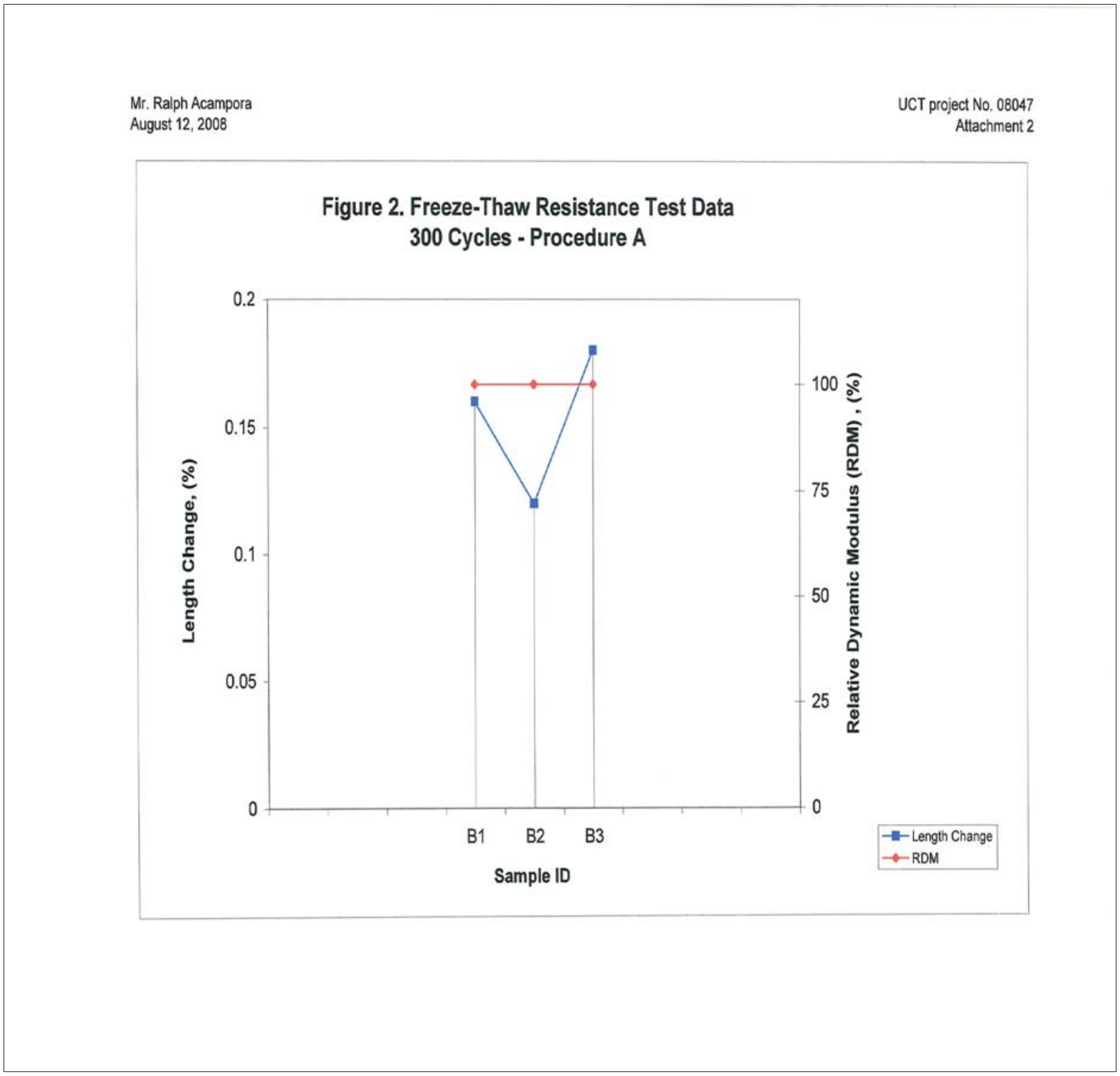

Table 7: UCT Test #08047
Freeze-Thaw – Length Change

The findings, based on the results of these tests conclude that strip strength is reached in less time, producing a possible savings in cement, and production hours. It also concludes that a less permeable more durable product is created with excellent freeze-thaw results.

TEST RESULTS: BLAKESLEE PRESTRESS CASE STUDY

Testing and resulting conclusions were done under the auspices of Advance Testing, Campbell Hall, NY. Tables 8 and 9 show the test results of the chloride permeability of concrete with and without an accelerator (Coulomb Test) using test methods of ASTM C1202 and AASHTO T277.

Table 8: RESULTS Test #1 No Accelerator - Project #070257 Lab #08-0236A Chloride Permeability of Concrete (Coulomb Test), test methods ASTM C1212, AASHTO T277

Specimen 1	Charge Passed Coulombs	Chloride Ion Penetrability
A	1291	Low
B	1213	Low
Average	1252	Low

Table 9: RESULTS Test #2 With Accelerator - Project #070257 Lab #08-0236B Chloride Permeability of Concrete (Coulomb Test), test methods, ASTM C1212, AASHTO T277

Specimen 1	Charge Passed Coulombs	Chloride Ion Penetrability
A	1572	Low
B	1602	Low
Average	1587	Low

INTERNAL CURING AND BRIDGE DECKS

Internal Curing has been used successfully in a number of short and medium span bridges. We will look at two such bridges: one in NY and the other in Ohio.

2007 OHIO DOT PROJECT 582-05: Route 84 Bishop Road Overpass of I-90 Spur - ODOT District 12, Cleveland, Ohio

PREPARING FOR THE POUR

Three days prior to the actual placement of May 7, 2007, in Cleveland, 2 truckloads of pre-saturated (IC) were ordered. LWA is stored on a concrete slab and subjected to an effective water spray system, ensuring continuous, thorough saturation of the product prior to shipment.

As a standard practice, upon arrival the material was discharged into a familiar open bunkered bin surrounded by concrete blocks. The material was handled and treated no differently than coarse lightweight aggregate utilized in other applications. The IC stockpile was sprinkled continuously up until two hours prior to batching to allow excessive free moisture to drain.

After the free water was allowed to drain from the stockpile material, the IC moisture contents were measured for free moisture and for the internally absorbed moisture that would later provide internal curing after placement, consolidation and finishing operations had ceased. Once calculated, batching adjustments were made to compensate for the free moisture content. After the mix adjustments were made, the material was picked up by a front-end loader and conveyed into an empty overhead bin for batching. Table 10 shows the results of this testing.

Table 10: COMPREHENSIVE STRENGTH RESULTS: ASTM C39
2007 OHIO DOT PROJECT 582-05

7 Days	5580 psi average
28 Days	7542 psi average (high break = 7930)
Non-IC 28 day breaks	5500-6500 psi average per ODOT

SHRINKAGE/CRACKING RESULTS:
RESTRAINED RING TEST ENDORSED BY AASHTO & ASTM

28 Days	No cracks reported

2008 NEW YORK STATE DOT PROJECT #D-260572: Twaalfskill Bridge, Lloyd, NY

DESCRIPTION:

Phase 1 of a 2 year project on NYS Route 9W requires the construction of a new, wider, more sustainable structure to accommodate higher vehicular traffic. Due to positive test results from extensive research, LWAS for IC was selected based on its ability to minimize cracking in the High Performance Concrete (HPC) deck. Its use improves on all the characteristic of concrete. This is accomplished by substituting a small amount of LWAS for some of the natural sand in a yard of concrete. Storage and batching procedures are the same as those followed for the ODOT project.

PREPARING FOR THE POUR

Storage and batching procedures are the same as those followed for the ODOT project. Table 11 shows the result of this testing.

Table 11: COMPRESSIVE STRENGTH RESULTS: ASTM C39
2008 NEW YORK STATE DOT PROJECT #D-260572

14 Days	5200 psi average
28 Days	7800 psi average

DISCUSSION OF CASE STUDIES

Concrete can be improved by substituting a small amount of natural sand in the concrete mixture with an equal volume of crushed structural grade absorbent lightweight aggregate sand at the rate of 200lbs/cubic yard.

Internal curing increases cement hydration and strength development, eliminating or reducing autogenous shrinkage and cracking. There is an increase in durability as well as a reduction in permeability, with is even more significant than strength gain. This feature insures ensures an extended life expectancy far beyond prior expected years, working well with blends of additional cementitious materials in particular. In order for the pozzolanic reaction to be effective it is absolutely dependent on the availability of moisture. In reality 200 pounds of LWAS carries the equivalent of approximately five gallons of absorbed water evenly dispersed (separate from the mixing water) throughout a yard of concrete.

HIGH PERFORMANCE CONCRETE (HPC) TOGETHER WITH INTERNAL CURING (IC)

High performance concrete (HPC) together with Internal curing (IC) reduces autogenous shrinkage and cracking, hydrating more of the cement and increasing strength from the first 24 hours and beyond. By keeping the relative humidity high, self-desiccation is reduced, which in turn reduces chloride permeability and improves durability. In addition, this may also afford an opportunity for cement savings.

Increased cement hydration results in higher earlier strengths as soon as 12 hours. The increases experienced in full-scale production ran on average between 10% and 15%, which carried over through 28 days.

High strength concrete alone does not guarantee high performance concrete. Many times high strength concrete experiences early-age cracking. The addition of LWAS at SSD provides for significant reduction in early age cracking. The area where cracking occurs is often referred to as the contact zone. The contact zone is the area where the cement mortar and the surface of the aggregate meet. Improving the tensile strength in this area, results in extended life cycle performance. Figure 9 shows the contact zone in W.P. Lane Memorial Bridge, over Chesapeake Bay, Annapolis, MD.

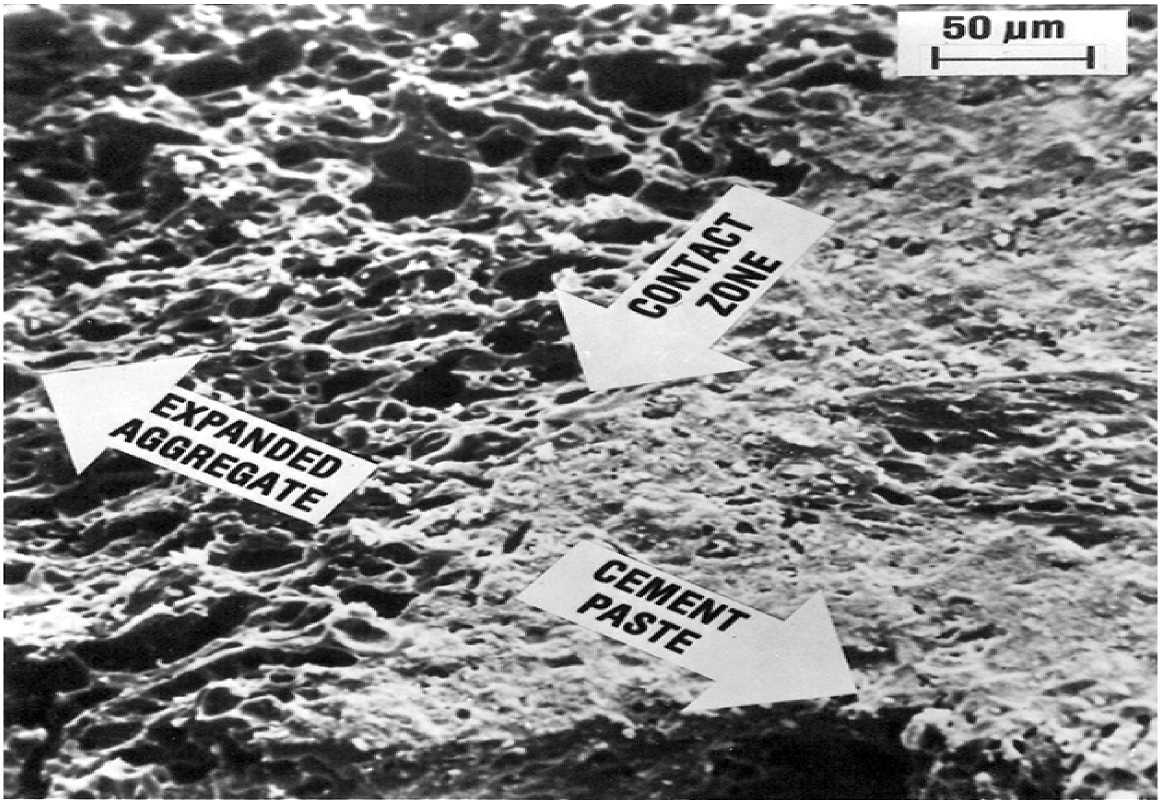

Figure 9: Contact zone in portion of concrete W.P. Lane Memorial Bridge, over Chesapeake Bay. Annapolis, MD

CONCLUSIONS

Precast and prestressed concrete can benefit from IC in that it improves compressive strength, MOE and reduces the permeability and cracking of the concrete. Internal curing may also benefit other areas of the manufacturing process including bed cycle time.

Self-consolidated concrete (SCC) can be benefited by IC because of its low water-cement ratio. SCC needs optimum gradations of materials to enhance the rheology and segregation resistance of the mixture. LWAS can be used to improve the overall gradation of the mixture.

Internal curing benefits high performance concrete by providing additional moisture within the dense inner structure of the concrete. The extra moisture allows for optional strength development of all cementitous and pozzolanic components. This will result in a more durable and sustainable concrete product.

ACKNOWLEDGEMENTS

The authors wish to thank:

Mr. John W. Roberts, Founder & Chairman of the Board
Northeast Solite Corporation; ACI Internal Curing Committee #308

Mr. Dale P. Bentz, Chemical Engineer
Material and Construction Research Division, National Institute of Standards and Technology (NIST)

Mr. Mario Bertolini, President
Blakeslee Prestress, North Branford, CT