

Internal Curing

Helping Concrete Realize its Maximum Potential



Both slabs installed within minutes of each other. No conventional curing on either slab. Photograph taken 24 hours later.

Internal curing offers benefits of improved hydration, reduced chloride ingress, and reduced early age cracking, which helps concrete achieve its maximum potential as a sustainable building material by extending its service life.

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Internally cured concrete is not a new concept; some might even say it is ancient since it can be considered to date back to concrete constructed during the Roman Empire. What is new, however, is a more complete understanding of how internal curing (IC) works and a way to design for IC. We also have a better understanding of why IC increases the durability and service life of concrete in an economical and practical way.



What is Internal Curing?

Internal Curing is a practical way of supplying additional curing water throughout the concrete mixture. This is done by using water absorbed in expanded shale, clay or slate (ESCS) lightweight aggregate, which replaces some of the conventional aggregate in the mixture. IC is often referred to as “curing concrete from the inside out.” ACI (2010) defined internal curing as *“supplying water throughout a freshly placed cementitious mixture using reservoirs, via pre-wetted lightweight aggregates, that readily release water as needed for hydration or to replace moisture lost through evaporation or self-desiccation.”*

While internal curing occurs in conventional light-weight concrete, it is only recently that internal curing has been intentionally incorporated into normal weight concrete to improve its properties.

Why is Internal Curing Used?

Internal curing provides something that most concrete needs and conventional curing cannot provide: additional water that helps prevent early age shrinkage and increases hydration of cementitious materials throughout the concrete. Although IC has shown benefits at w/cm up to 0.55 (Espinoza-Hijazin and Lopez, 2010), the need for internal curing increases as the w/cm is lowered. Research shows that even in moderate w/cm (0.40 to 0.46) mixtures, the cement hydration is often not nearly complete, even after many months.

Once concrete sets, hydration creates partially-filled pores in the cement paste which causes stress that results in shrinkage. IC provides readily available additional water throughout the concrete, so hydration can continue while more of the pores in the cement paste remain saturated. This reduces shrinkage and early age curling/warping, increases strength, and lowers the permeability of the concrete, making it more resistant to chloride penetration.

Internal curing has been shown to work well with supplementary cement materials (SCM), especially at higher dosage levels, because fly ash and slag have increased water demand during their reaction, compared to hydrating portland cement.

Internal curing does not replace conventional surface curing, but works with it to make concrete better. Internal curing can also help compensate for less than ideal weather conditions and poor conventional curing that is often seen in the real world.



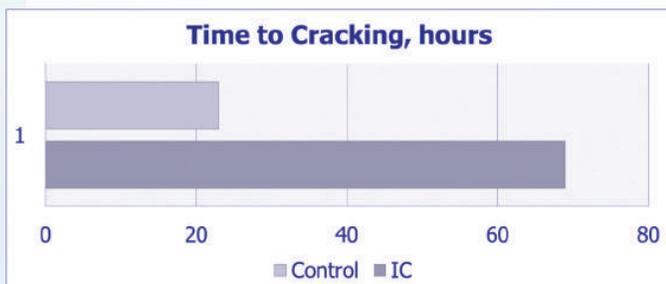
What are the Benefits of Internal Curing?

The primary benefits of IC are more durable and less permeable concrete. These benefits are provided in three ways. First, improved cement hydration and SCM reaction reduces the porosity of the concrete. Second, IC improves the interfacial transition zone causing it to be "almost nonexistent" at the LWA. Third, the additional curing water provided by IC minimizes the internal autogenous stresses due to self-desiccation, resulting in reduced early age cracking and reduced overall cracking.

The even distribution of additional water sources within the concrete will lead to greater uniformity of moisture throughout the thickness of the section, and thus reduced internal stresses due to differential drying. While drying shrinkage may not be completely prevented in the long term, delaying it will allow the mixture to gain strength and be better able to resist the associated stresses.

The concrete benefits from Internal Curing with

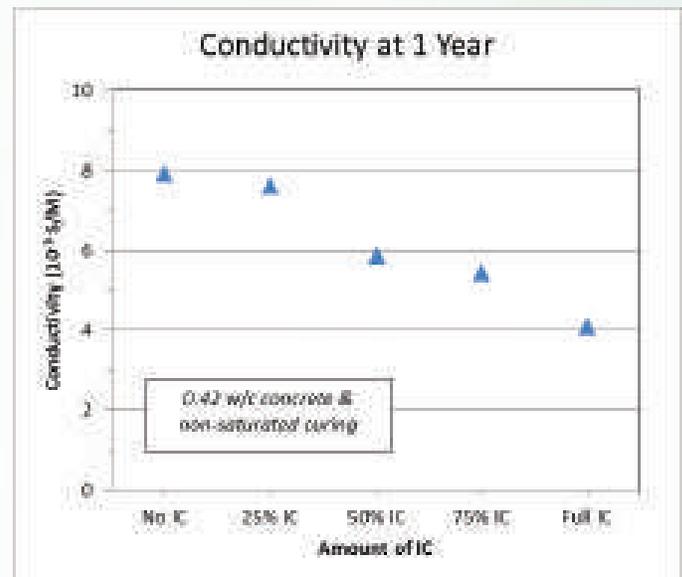
- Increased cement hydration and SCM reaction
- Improved microstructure of the cementitious paste
- Less shrinkage (Fewer micro-cracks resulting in overall less cracking and smaller cracks)
- Improved interfacial transition zone
- Lower permeability (Reduced fluid transport, less chloride penetration)
- Increased strength and durability
- Reduced modulus of elasticity resulting in less cracking
- Less early age curling and warping
- Reduced coefficient of thermal expansion



Summer curing temperature profile for expanded shale IC mix compared to control at 0.42 w/c. Byard & Schindler 2010 Auburn University Study

The construction process benefits from Internal Curing with

- Compensation for poor jobsite curing as well as support for proper curing
- Tolerance of higher curing temperatures without cracking or strength reduction
- Reduced early age curling and warping
- Reduced heat of hydration through the use of additional SCMs
- Reduced design loads and transportation costs because of lower concrete densities
- Improved workability and finishability because the additional IC water helps to eliminate some of the sticky properties commonly found in concretes utilizing SCMs



Reduced electrical conductivity at 1 year for non-sealed ("real world") conditions (Castro, 2011)

Society and owners benefit from improved sustainability with

- Increased service life
- Improved economies by lowering life cycle cost
- More efficient use of cement
- Higher percentage of SCMs to be utilized in concrete reducing carbon footprint of the mixture

What is ESCS Lightweight Aggregate?

ESCS is a manufactured ceramic aggregate produced by expanding and vitrifying shale, clay or slate in a rotary kiln. The process produces a porous, low density, strong and durable aggregate that is dimensionally stable over time.

The pore structure in ESCS allows it to absorb water and then readily release it to hydrating cement paste. Research has shown that ESCS manufactured in North America will release over 85% of its absorbed water at relative humidity of 94% or higher. This has been found to be the optimal level of desorption for IC to occur (Castro et al., 2011).

What is “Sustainable” About Using ESCS for Internal Curing?

Some additional cost, energy and emissions will be associated with manufacturing ESCS lightweight aggregate, but these are lower than the savings realized due to its use. In general, 100 lb. of ESCS generates about 18 lbs. of CO₂ (ESCSI, 2006), which is roughly equivalent to the amount of CO₂ created by manufacturing 18 lbs. of portland cement. Considering the significant potential to increase the service life of the concrete, reduce the amount of cement and increase the use of SCM, internal curing is a practical way to increase the sustainability of concrete. However, the carbon footprint for each mixture should be individually evaluated based on the balance of CO₂ from cement reduction, increased SCM use and the potential increase in service life.

How is an Internal Curing Mixture Designed?

The aggregate size used for IC is normally a fine grading that replaces a portion of the normal weight mixture’s sand fraction. The fine grading provides a more even distribution of the IC water throughout the cementitious paste. The same amount of water concentrated only in coarse ESCS aggregate can leave part of the cementitious paste “un-protected” by IC. This is because the water only travels a limited distance (on the order of 2 to 20 mm) depending on age and w/cm. In some mixtures, intermediate size aggregate may be used to optimize total aggregate grading, as well as provide IC.

The amount of wetted ESCS aggregate needed is based on the absorption and desorption of the aggregate being used. For most practical concrete applications, 7 lbs. IC water/100 lbs. cementitious material provides an appropriate value for the amount of IC moisture needed. However, the amount of IC water may be increased to accommodate evaporation or to satisfy the higher water demand in mixtures with SCMs.

Knowing the target amount of IC water needed and the aggregate’s absorption and desorption, the amount of prewetted ESCS aggregate can be determined through the use of ESCSI’s “Guide for Concrete Mixture Designs using Prewetted ESCS Lightweight Aggregates for Internal Curing” (2011) or by contacting the ESCS lightweight aggregate supplier.





Where has Internal Curing Been Used?

Although the concept of IC may be new to many in the concrete industry, it is an automatic side benefit anytime prewetted ESCS is incorporated in a concrete mixture. This includes thousands of projects over the last 90 years. Since 2003, over 2.0 million yd³ of internally cured normal weight concrete, including 1.3 million yd³ in low slump pavements, have been placed. Some of the more recent projects that have incorporated wetted ESCS into a normal weight concrete mixture for the specific purpose of internal curing are:



The Union Pacific Intermodal Terminal, Hutchins, TX

project started in 2005 and incorporated over 250,000 yd³ of internally cured concrete. The mixture used 5 ft³ bulk volume of an ESCS intermediate grading (3/8 in. to No. 8) in each cubic yard of concrete to replace a portion of both the normal weight coarse and fine aggregate. This enhanced both the cementitious hydration and overall aggregate grading of the mixture, which resulted in the mitigation or elimination of plastic and drying shrinkage cracking. The average strength gain was about 1000 psi with a 200 lbs./yd³ reduction in density which translates to 2000 lbs. less weight per 10 yd³ load of concrete (Villarreal and Crocker, 2007).



Texas State Highway SH 121 incorporated 1300 yd³ of internally cured concrete on one side of a 5 mile section near Dallas in November 2006. A 500 ft long section of continuously reinforced concrete pavement (without joints) was evaluated for cracks on February 1 and again on September 11, 2007. The side with IC showed 21 cracks. In comparison, the normal weight

control on the other side of the road showed 52 cracks. In addition, the crack width was considerably smaller on the side with the internally cured concrete.



New York State has incorporated the use of prewetted lightweight ESCS fines into numerous bridge decks throughout the state. Thousands of cubic yards of internally cured concrete were specified to reduce cracking associated with low permeability concrete that incorporated SCMs into the mixture. These structures are exposed to high traffic volume and have high exposure to de-icing chemicals because of the severe climate.

The State of Indiana began their transition of IC technology from laboratory research to the field with two bridge decks near Bloomington cast in September 2010 (Fig. 1). The bridges had similar design and were constructed with the same methods and materials supplied from the same ready mix company. One deck used a conventional bridge deck concrete mixture, while the other internally cured bridge deck had approximately 55% of the fine aggregate replaced with lightweight aggregate. One finisher noted that the IC mixture was less “sticky” and slightly easier to work with.

Observations include equivalent strengths at 10 days, and at 3 months the internally cured concrete was 20% stronger. Rapid chloride permeability for the IC mixture was 10% lower at 28 days and nearly 40% lower after 3 months. The internally cured mixture also had a lower shrinkage. It was also notable that cracks developed in the conventional deck after the first few months of service (Fig. 2), while the internally cured concrete had no visible cracking after nearly one year (Fig. 3).



What is the Recent History and Development of Internal Curing?

The first modern awareness of internal curing dates back to the mid 1950s when Paul Klieger (1957) wrote, *"Lightweight aggregates absorb considerable water during mixing which apparently can transfer to the paste during hydration."* Campbell and Tobin (1967) confirmed this with a comprehensive program that showed the availability of absorbed moisture in lightweight aggregate produced a more forgiving concrete that was less sensitive to poor field curing conditions.

In the early 1990s, the benefits of internal curing came to the concrete industry forefront. Robert Philleo (1991) stated, *"Either the basic nature of Portland cement must be changed so that self-desiccation is reduced, or a way must be found to get curing water into the interior of high-strength structural members. The latter is possible through the use of saturated lightweight aggregate. However, people striving for high strengths are not eager to use lightweight aggregate. A partial replacement of fine aggregate with saturated lightweight fines might offer a promising solution."*

Structural lightweight aggregate was used on the Hibernia Offshore Platform in Newfoundland, Canada to improve buoyancy by replacing 50% of the coarse aggregate with a prewetted ESCS. The benefits of internal curing quickly became apparent on this innovative use of high strength lightweight concrete, which spawned new research on the subject in the mid 1990s. Around 2000, the National Institute of Science and Technology (NIST) started an extensive investigation of IC.



Since then, IC has been widely investigated with well over 100 papers published to date. One recent significant report, "Internal Curing: A 2010 State-of-the-Art Review," by Bentz and Weiss (2011) covers the subject in depth.

What is the Underlying Theory and Goal of Internal Curing?

The need for internal curing emanates directly from the basic nature of cement hydration reactions. Conventional curing, especially in quality concrete, may only penetrate a few millimeters into the concrete. Once concrete sets, chemical shrinkage continues in the cement paste as hydration progresses and creates partially-filled pores within the microstructure of the concrete. These unfilled pores in the cement paste create capillary stress, which causes shrinkage. Internal curing provides readily available additional



water throughout the concrete, so more of the pores remain water-filled, minimizing stress and strain development. This reduces or eliminates early age cracking of the concrete and promotes

maximization of cement hydration, potentially contributing to increased strength and reduced fluid transport coefficients. The goal of internal curing is to provide additional water in the proper amount with a proper spatial distribution so that the entire three-dimensional microstructure of hydrating cementitious paste remains saturated and autogenous stress free (Bentz and Weiss, 2011).

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Expanded Shale, Clay and Slate Institute
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