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**Tech Brief**

# Internal Curing for Concrete Pavements

*This Tech Brief provides information on internal curing for concrete pavements by describing the primary concepts behind internal curing as well as describing aspects of practical applications, mixture design, construction, and quality control.*

## INTRODUCTION

Internal curing provides a modern twist on good curing practice by providing water to the cementitious matrix after setting. Internal curing improves the performance of concrete by increasing the reaction of the cementitious materials. However, unlike conventional curing that supplies water from the surface of concrete, internal curing provides curing water from the aggregates within the concrete (Figure 1). This is very beneficial since the depth that external water can penetrate is limited for any concrete, while internal curing water is dispersed throughout the depth of the concrete. In North America, this water-filled inclusion is typically an expanded lightweight aggregate, although superabsorbent polymers, cellulose fibers, or recycled concrete have been used (1, 2, 3).

The water that is absorbed in the lightweight aggregate does not contribute to the classic definition of the water-to-cement ratio. The water-to-cement ratio is a descriptor of structure of the matrix and pores that develop in the fluid concrete system. Once the concrete sets, the structure and pore network have been established, and water can only aid in hydration. The water in the lightweight aggregate will desorb (leave) the pores of the lightweight aggregate as the negative pressure in the pore fluid develops with setting and increases thereafter.

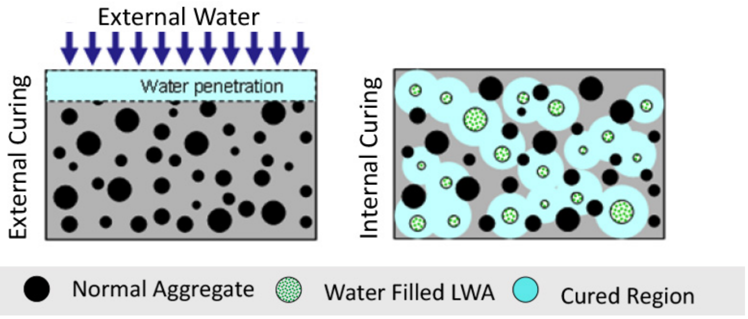

***Figure 1.*** *An illustration of conventional curing as compared with internal curing.*

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Internal curing also can reduce autogenous shrinkage, since water from the lightweight aggregate will work to fill pores that otherwise can lead to autogenous shrinkage. The water from the pores may eventually be lost to the environment; however, there are benefits in reducing the rate of shrinkage (4). Internal curing also can reduce transport properties (permeability, diffusion, and sorption) through increased hydration of the interfacial transition zone around the lightweight aggregate (2). Internal curing is especially beneficial for mixtures containing high volumes of supplementary cementitious materials that may require longer times to hydrate (2). Internal curing can also make concrete less susceptible to thermal cracking, as the “built-in” stress caused by autogenous shrinkage is substantially reduced (2). Many additional benefits are being investigated, such as benefits in terms of reduced curling (5).

## PAVEMENT APPLICATIONS

Internally cured concrete has mostly been used in bridge deck applications to date; however, researchers have investigated extending the use of internal curing to pavements (5). The following sections describe recent activity in continuously reinforced concrete pavements, jointed plain concrete pavements, concrete patches, and concrete overlays.

### *Continuously Reinforced Concrete Pavement*

It has been speculated that the use of internal curing in mainline paving is likely most beneficial to continuously reinforced concrete pavement (CRCP) due to the reduction in shrinkage and curling, which may result in increased mechanical performance and fatigue capacity (6). Observations of CRCPs have indicated that early shrinkage is significantly reduced as compared with conventional concrete, resulting in early crack spacing patterns of approximately three times those developed in conventional concrete pavement sections (6). Longer term monitoring has shown that this difference in crack spacing decreases over time until the spacing is on the order of 20 to 30 percent longer than that in conventional concrete. However, cracks that occur at later ages are smaller than those that develop at earlier ages. This phenomenon has been observed in in-service pavements in which the cracks in internally cured concrete remain tighter than those in conventional concrete (6).

In some cases, the use of internally cured mixtures for CRCPs has resulted in a reduction in concrete elastic modulus, which results in a reduction in stresses which, combined with lower coefficient of thermal expansion and improved strength, provides a reduction in fatigue damage. This is somewhat affected by which aggregate sizes are introduced in the internally cured concrete modification and whether the additional aggregate is used to develop an optimized mixture. In such instances, the resistance of the concrete to flexure cracking is increased, which improves pavement performance life (6).

Pavement performance prediction using the Pavement ME Design software also has indicated that the incorporation of internal curing in CRCP will result in slightly longer crack spacing and tighter cracks. These changes are predicted to significantly increase the performance life of the pavement as compared with conventional concrete used in the same design (6).

It has also been reported that internal curing will result in a reduction in moisture-related curling/warping (7). Research has also found that internal curing reduces curling, compared to an equivalent mixture without fine lightweight aggregate. The tendency toward a uniform moisture gradient may reduce slab curling and warping due to overall temperature and moisture gradients; however, a reduction in curling from moisture gradient alone would be very beneficial in pavements.

The benefits of internal curing in CRCPs are being investigated in a study for the Illinois Tollway. Neutron radiography is being used to examine moisture gradients, and full test sections are planned to be cast during the summer of 2016 (8).

### *Jointed Plain Concrete Pavement*

Internal curing in jointed plain concrete pavements appears to have positive effects on issues known to influence structural longevity and durability. Small reductions in unit weight, elastic modulus, and coefficient of expansion together with a small increase in strength promote improved structural integrity. The combined effect of these small improvements results in a significant positive impact on slab fatigue damage and associated slab cracking in jointed concrete pavements (6). The extended moisture supply provided by internal curing improves concrete pavement durability by reducing net moisture loss and improving hydration.

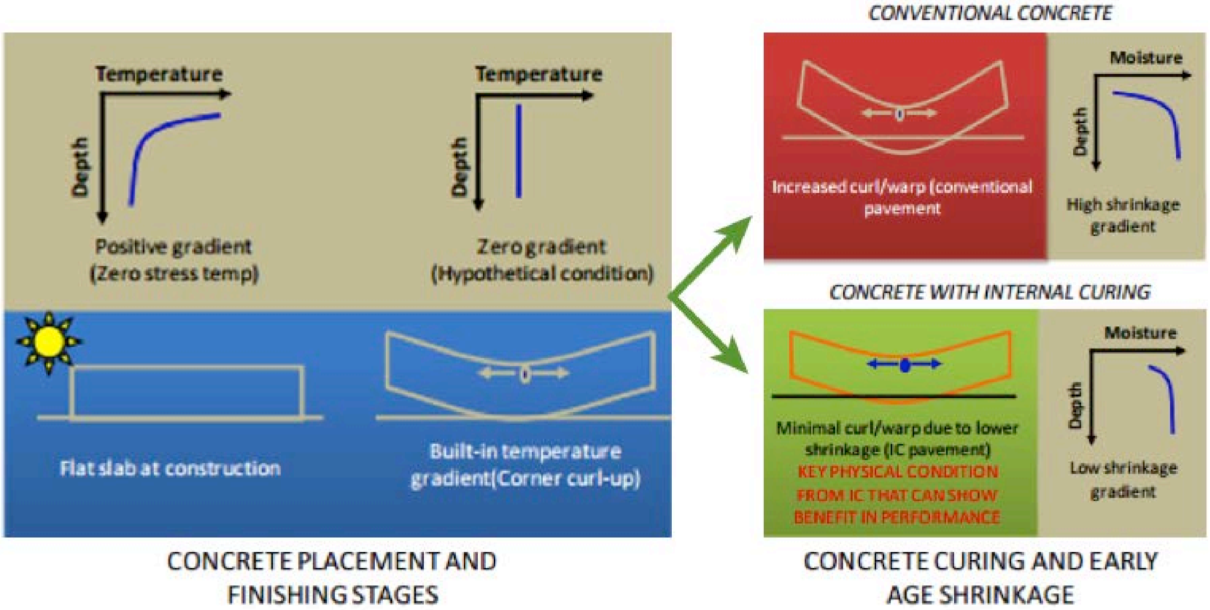

***Figure 2.*** *Construction-related permanent built-in temperature and shrinkage gradients.*

Internal curing reduces early age shrinkage and associated plastic shrinkage cracking, as evidenced in both laboratory and field monitoring of concrete placements.

Another potential benefit to jointed pavements is a reduction in upward slab curling resulting from internal slab moisture gradients and stresses locked in at the time of set resulting from temperature gradients during curing. Stresses resulting from curling, when combined with load-induced stresses, can accelerate damage to pavement slabs. This reduction in curling stresses can improve pavement performance by reducing the total stress level, thereby limiting damage to pavement slabs (Figure 2).

### *Patching and Full-Depth Panel Repair*

While the vast majority of field trials have focused on the use of internal curing for bridge decks (5), field trials performed in Indiana (9) in 2014 used internal curing with expanded slag aggregate in high early-strength, full-depth concrete pavement patches (Figure 3). The application of internal curing in the high early-strength patches provided a concrete with two distinct benefits when compared with conventional concrete: 1) reduced built-in stress caused by the restraint of shrinkage, which resulted in reduced cracking, and 2) increased water curing (from inside the concrete) after the patches are covered with curing compound and opened to traffic.

***Figure 3.*** *Internally cured mixtures being used for panel replacement.*

## MIXTURE DESIGN FOR INTERNAL CURING

Except for the lightweight aggregate, internally cured concrete mixture design generally is identical to that of conventional concrete with similar air content, water content, and coarse aggregate content. Currently, internal curing in North America is typically achieved by replacing a portion of the conventional fine aggregate (i.e., sand) with a pre-wetted lightweight fine aggregate. This practice occurs mainly due to lightweight aggregate availability, economics, and the fact that the fine lightweight aggregates already appear on the approved materials lists of many state highway agencies. Fine lightweight aggregate is generally preferable to coarse lightweight aggregate because:

- The fine lightweight aggregate can provide sufficient distribution of the curing water across the cross section to enable the internal curing water to reach the matrix.
- The use of conventional coarse aggregate provides conventional stiffness and fracture properties for the concrete.
- The fine lightweight aggregate is generally less expensive than the coarse lightweight aggregate.
- The fine lightweight aggregate can be evaluated using ASTM C1761 (10), although expanded clay, shale, slate, and slag have all been used effectively for internal curing.

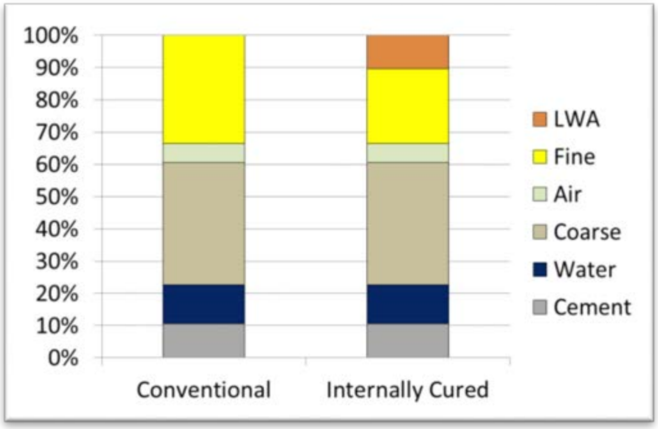

**Figure 4.** *Typical mixture proportion volumes.*

Figure 4 provides an example of the volume proportions of conventional and internally cured concrete. The figure illustrates the similarities and differences between the design of a conventional six-bag mixture (water-to-cement ratio of 0.36 and 6 percent air) and an internally cured mixture using the same volume proportions of the constituents. The example assumes 15 percent absorption of the fine lightweight aggregate and a volume of internal curing water that is equivalent to the volume of chemical shrinkage of a typical cement (7 lb of water for every 100 lb of cementititous materials).

The volume of sand that is replaced with fine lightweight aggregate will vary depending on the properties (porosity and desorption) of the fine lightweight aggregate and the design assumption (providing internal curing water to equal chemical shrinkage or providing some other amount of internal curing water). Using the mixture design from Figure 4 and assuming that the internal curing water is designed to replace the chemical shrinkage water, an example to illustrate the mixture design for the wide range of expanded lightweight aggregates in North America (considering the properties of the lightweight aggregate such as specific gravity, 24-hour absorption, desorption) is shown in Figure 5.

There is a wide range of tools that can be used to proportion a specific mixture; however, a simple spreadsheet is available to convert a conventional mixture design to an internally cured mixture design in a simple step using the properties of the lightweight aggregates (5). This spreadsheet, along with the majority of internal curing conversion tools, has been designed with a volume of internal curing water that is equal to the volume of chemical shrinkage to negate the effects of self-desiccation. It is possible to design at differing levels of internal curing water, which may be done to account for the majority of internal curing benefits for a lower-cost mixture or to compensate for drying shrinkage or other sources of water loss.

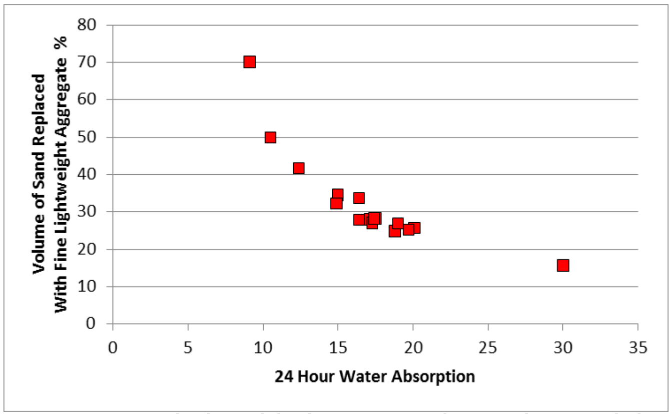

**Figure 5.** *Relationship between absorption and the volume of fine aggregate replaced with fine lightweight aggregate.*

## CONCRETE PAVEMENT CONSTRUCTION ASPECTS OF INTERNALLY CURED CONCRETE

The production of internally cured concrete is similar to that of conventional concrete, but understanding and controlling the aggregate moisture is more critical in internally cured concrete in order to have a consistent mixture due to the higher absorption values in the fine lightweight aggregate. The lightweight aggregate is pre-wetted in a stockpile prior to batching with a sprinkler or soaker hose for 48 hours before allowing a drain-down period of at least 12 hours, which enables the reduction of surface moisture and greater uniformity throughout the stockpile.

The process for batching internally cured concrete is similar to that for conventional concrete. An extensive study noted that batching was performed easily, with no problems being reported due to the addition of the lightweight aggregate other than the need for an additional bin for the pre-wetted lightweight aggregate (9).

The absorbed moisture and surface moisture in the lightweight aggregate should be carefully measured and controlled to reduce the amount of variability from batch to batch. Two methods are commonly used to determine the aggregate absorption and surface moisture: the paper towel method and the centrifuge method. The centrifuge has been shown to be faster and more accurate than the paper towel method (9).

Most conventional quality control tools used for conventional concrete apply to internally cured concrete as well. It has also been noted that entrained air content can be measured using either ASTM C173 (the pressure method) or ASTM C231 (the volumetric method) when fine lightweight aggregate is used (11). This is an important finding, as it indicates that the more rapid, conventional pressure method can be used even though fine lightweight aggregate is being used, presumably due to the lightweight aggregate being well saturated before testing.

## PROPERTIES OF INTERNALLY CURED CONCRETE

The direct benefits of internally cured concrete include a reduction in autogenous shrinkage, a reduced rate of drying shrinkage, reduced elastic modulus, and improved hydration. Rao and Darter indicated that, in addition to these benefits, the combined effects of unit weight reduction, strength increase, and coefficient of thermal expansion reduction add up to a significant positive impact on slab fatigue and associated cracking initiating both from the top of the slab and the bottom of the slab (6). There also exists a potential for reducing the opening of shrinkage cracks (including sawed joints), which improves the shear transferability of the cracks and joints, leading to higher load transfer efficiency and longer service life.

Rao and Darter also explored the practicality of incorporating internally cured concrete properties in the performance predictions produced by the Pavement ME Design software (6). They also considered the impact of internally cured concrete on concrete pavement life-cycle cost analysis results and presented a roadmap for continued progress in the application of internally cured concrete in concrete pavements.

## PRACTICAL APPLICATIONS

Internally cured concrete has been used for many concrete facilities, the majority of which have been bridge structures. However, as noted below, there have been a number of pavement applications, primarily in the Dallas-Fort Worth area (12). The pavements in the Dallas area used a relatively small substitution of intermediate aggregate sizes with lightweight aggregate. Some examples of the projects in Texas include:

- A 1,400-foot section of CRCP on the outer lane and shoulder of State Highway 121 north of Dallas in 2006. The remainder of this project was constructed with conventional concrete to enable a performance comparison. Follow-up surveys indicated that the initial crack pattern that developed in the internally cured section exhibited much longer spacing than is normal for CRCP, and the cracks are also much tighter. After several years, the crack spacing became similar to that of the conventional sections; however, the cracks remained much tighter.
- A high early-strength mixture in a section of an off ramp on I-635 for early opening to traffic in 2012. The use of internal curing had no adverse effect on early strength and was able to reducing shrinkage cracking.
- A 360-acre Union Pacific intermodal terminal located 12 miles from downtown Dallas, within the city limits of Hutchins and Wilmer. Minor joint spalls and limited cracking have been observed. Performance has been similar to the conventional sections, with both in excellent condition.
- A residential subdivision in south Fort Worth, Windsor Park, constructed in 2006-2007. A survey after 8 years in service identified no significant longitudinal or transverse cracking, plastic shrinking cracking, spalling, or other defects. In general, the pavement was in excellent condition.
- A residential subdivision in north Fort Worth, Alexandria Meadows North, constructed in 2006-2007. This project contained streets both with and without internally cured concrete. A field survey revealed both the internally cured concrete and conventional pavement sections

***Table 1.*** *Example mixture designs showing the replacement of normal weight aggregates with expanded shale lightweight aggregates (shown in bold font).*

| **Mixture Component** | **Control** | **Internally Cured** | **Coarse Lightweight Aggregate Mix** | **All Lightweight Aggregate Mix** |
|---|---|---|---|---|
| Water (lb/yd$^3$) | 260 | 260 | 276 | 276 |
| Cement (lb/yd$^3$) | 620 | 620 | 658 | 658 |
| SSD normal weight coarse aggregate (lb/yd$^3$) | 1761 | 1761 | *0* | *0* |
| **WSD shale lightweight coarse aggregate (lb/yd$^3$)** | **0** | **0** | **933** | **948** |
| SSD normal weight fine aggregate (lb/yd$^3$) | 1210 | 878 | 1354 | 0 |
| **WSD shale lightweight fine aggregate (lb/yd$^3$)** | **0** | **230** | **0** | **908** |
| Water-reducing admixture (oz/yd$^3$) | 31 | 31 | 0 | 0 |
| High-range water-reducing admixture (oz/yd$^3$) | 0 | 0 | 39.5 | 16.5 |
| Rheology-controlling admixture (oz/yd$^3$) | 0 | 0 | 0 | 79.0 |
| Air-entraining admixture (oz/yd$^3$) | 0.8 | 0.8 | 6.6 | 2.9 |
| Target total air content (%) | 5.5 | 5.5 | 5.5 | 5.5 |
| Water-to-cement ratio | 0.42 | 0.42 | 0.42 | 0.42 |

were in excellent condition, with very limited cracking. No slab curl was identified.

The mixtures used in the aforementioned studies used intermediate size lightweight aggregate. Table 1 provides an example of one such mixture design that was used on the Union Pacific intermodal facility in Dallas-Fort Worth. This table provides the mixture proportions for both conventional and internally cured concrete mixtures.

The two key benefits determined for internally cured concrete in concrete pavement are structural longevity and durability. Structural longevity is improved with internally cured concrete due to its small reduction in unit weight, elastic modulus, and coefficient of expansion, and a small increase in strength. These small effects, when combined, amount to a significant positive impact on slab fatigue damage and associated slab cracking in jointed concrete pavements. Likewise, internally cured concrete leads to tighter crack openings and reduced punchout failures for CRCP. Several case studies were analyzed using the Pavement ME Design procedure, and the results indicated improved performance and longer lives for internally cured concrete sections. Life-cycle cost analyses for these projects showed generally lower costs for internally cured concrete as compared to conventional concrete (6).

## SUMMARY

Internal curing of concrete has been the subject of many laboratory investigations over the last two decades. Internally cured concrete has been used successfully in full-scale bridge decks and in concrete for CRCP, jointed plain pavement, and pavement patching projects. Additional field trials are underway to examine the potential use of internally cured concrete in a variety of paving applications. Field experience to date has shown that, in general, internally cured concrete has similar workability, similar strength and mechanical property development, reduced stress development and cracking, and similar or improved durability when compared with conventional concrete. Specific improvements identified include reduced shrinkage, resulting in fewer and tighter cracks, improved fatigue resistance, and reduced slab curling/warping. Performance models, generated using the Pavement ME Design program, indicate that the performance of pavements made with internal curing should be superior to conventional concrete pavements, resulting in improved life-cycle cost.

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