"INTERNAL CURING IN PAVEMENTS, BRIDGE DECKS AND PARKING STRUCTURES, USING ABSORPTIVE AGGREGATES TO PROVIDE WATER TO HYDRATE CEMENT NOT HYDRATED BY MIXING WATER"

By:

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Transportation Research Board
83rd Annual Meeting
Washington, DC
January 11-15, 2004

Visual #1

Internal Curing (IC) has come of age and is being considered for many different types of uses in concrete construction to make good concrete better.

Visual #2

There are applications for IC in pavements, bridges and in parking structures, not only in new construction, but also in rebuilding, repair and maintenance. The reasons are that with IC there are greater early age strength, three-day strength greater than seven-day strength without it, almost no autogenous shrinkage and cracking, and lower permeability. With the lower cracking, there is greater protection of the reinforcing steel against salt attack, greater durability, (meaning increased service life), and earlier use of the concrete.

Autogenous shrinkage, which plagues the topical high performance concrete (HPC), can be controlled and concrete can be made stronger and otherwise improved by the substitution, for a small amount of natural sand in the mix, of an equal volume of crushed structural grade lightweight aggregate sand.

Visual #3

Most expanded shale lightweight aggregates have the ability to absorb 15 % or more by weight of water, and this absorbed water, when incorporated in a low water-cement (w/c) ratio concrete mixture, is immediately available to hydrate the cement particles deprived of mixing water. This occurs through prompt release of the water as the concrete cures and the mixing water is used up. This process is called Internal Curing.

Visual #4

The benefits of lightweight aggregates have been intuitively known by practitioners for years. The original Chesapeake Bay Bridge, built 50 years ago, used both coarse and fine lightweight aggregates with no air-entrainment.

The 4.2-mile (6.76 km) span out-lasted the approach decks of normal weight concrete.

Visual #5

Stanton Walker, who worked with Duff Abrams in the development of the water-cement (w/c) ratio, tested lightweight concrete in the NRMCA freeze-thaw labs for 200 cycles. Bryant Mather, three years ago, called Internal Curing “self-curing” concrete. His vision gives us the target to aim at, and when we hit it, we’ll have a “bull’s eye”. The eventual procedure needed for curing the millimeter or two near the surface when using IC will be established. In the meantime, we recommend that IC concrete be immediately fogged and covered with wet burlaps for seven days.

Over the years, lightweight concrete usually has not included lightweight sand, using only the coarse lightweight aggregate (¾ inch). The purpose was not of supplying the extra water in the mix to improve the performance, but for the economy of using it for its saving in weight in bridges and buildings or for its fire resistance. The replacement has been about 850 lbs (386 kg) of lightweight aggregate for 1800 lbs (818 kg) of natural coarse aggregate. All of the coarse fraction was lightweight and it usually has been used with natural sand. This has been economical in long span bridges. The same lightweight aggregate, crushed to sand size, is effective in short spans for Internal Curing (IC).

In normal weight concrete above a w/c ratio of approximately .45, drying shrinkage takes place and autogenous shrinkage is hidden. At .43 autogenous shrinkage is quite measurable, and with decreases in w/c to .40 and the .30’s autogenous shrinkage and cracking is more and more evident.

We have found that the replacement for natural sand in the mix of as little as 100 lbs (45 kg) of lightweight aggregate sand will supply the water needed to properly hydrate the cement in a concrete paving mix with a w/c of .434. For a bridge concrete mix, if the w/c ratio is less, a greater replacement is needed.

Lightweight sand provides a more uniform distribution of the water-giving particles than coarse aggregate can provide. Its greater dispersion makes absorbed water more closely available for the hydration of the cement that would otherwise not be hydrated in a low w/c ratio mix.

For short span bridges, using normal weight aggregate, problems arise with low w/c ratios. Low w/c ratios are desirable in order to limit drying shrinkage and cracking, but, the w/c ratio used in pavements and bridge decks using normal weight aggregate is at a level where autogenous shrinkage takes place, and with decreasing ratios accelerates. Thinking outside the box, what will allow us to use low w/c ratios and at the same time reduce the problems of autogenous shrinkage and cracking? One obvious and available answer is to provide in the mix a source of water, for instance, absorbent lightweight aggregate. The procedures and processing remain the same – just substitution for a portion of the natural sand with lightweight sand saturated with water

Visual #6

The release rate of water is relative to the absorption rate of the aggregate. It is important that much of the absorption take place in the first 30 minutes. The result is significant. The early capillary action in the first few hours up to a day or so causes much more hydration of the cement with large increases in strength. The distribution of the sand size lightweight aggregate throughout the mixture optimizes this result and reduces autogenous shrinkage. Because water is so fluid, because capillary action is so strong, and because the thirst of the cement particle so intense, all these actions take place simultaneously.

Drying shrinkage and cracking have been reduced through the use of low water-cement ratio concrete. Now, through Internal Curing (IC), we can further reduce cracking caused by autogenous shrinkage.

Visual #7

Simultaneous to the efforts all over the world to research the causes and effects of Internal Curing using absorptive lightweight aggregate, Dale Crowl and Mike Sutak of District 12 of the Ohio DOT spent 4 years inspecting 116 high performance normal weight concrete (HPC) bridge decks. They methodically isolated the potential shrinkage problem and came up with a solution. They ascertained that it was the materials used in the concrete mixtures. They identified materials of bridges that cracked and bridges that didn't crack.

They theorized that coarse limestone aggregate with absorption less than 1.00% might lead to cracking. They compared test data, and found that mixes without enough absorbed water can lead to autogenous shrinkage. The conclusion is that coarse aggregates with absorption values less than 1.00% in HPC can cause severe cracking in the bridge decks and recommended the use of stone with an absorption of at least 1.00%. Their recommendation also includes a w/c ratio lower limit of .42 to prevent autogenous shrinkage. Their field analysis correlates to our laboratory tests on lightweight aggregate sand.

Both sand-size expanded shale lightweight aggregate with an absorption of 15% and natural crushed limestone coarse aggregate with an absorption of over 1% have been identified through tests and/or experience to eliminate autogenous shrinkage. In concrete with a w/c ratio of .42 to .434 each aggregate type provides the same amount of absorbed waters, 15 lbs, to the mixture. One percent (1%) of 1500 lbs (682 kg) stone is equivalent to fifteen percent (15%) of 100 lbs (45 kg) lightweight sand.

Visual #8

Besides shrinkage and cracking, lets look at a number of characteristics improved by IC hydration. At a .434 w/c ratio, with 100 lbs (45 kg) lightweight replacement, permeability is improved 25%; flexural, compressive and tensile, strengths are improved 14, 10, and 6 respectively; durability 2%.

Visual #9

The 2, 7, and 28 day mortar strength test shows the contribution made by having a strong lightweight aggregate as well as an absorptive one, both important considerations. Good concrete can be made better by improving the characteristics of the paste. This comparison shows how beneficial the proper IC material can be.

Visual #10

To make the mortar stronger, it is important that the lightweight aggregate sand substituted for the normal weight sand have optimum characteristics. These are particle shape, particle strength, gradation, absorption (SSD) and rheology. The stronger the mortar, the more compatible it is to the coarse aggregate. Coarse aggregate is almost always the strongest part of the concrete; having the paste strength numerically close to that of the stone is helpful.

Visual #11

Internal Curing is for the purpose of enhancing the properties of the concrete. Toward this end it is essential to replace with absorptive aggregate that does not adversely affect any of the properties. It is essential that the replacement particles be strong enough so that the strength of the normal weight material being replaced is not compromised.

Increased early-age flexural strength is beneficial for applications in concrete pavements. Beside the reported benefits, there is an opportunity “for a contractor to place the concrete in service sooner”. The NYS DOT “is willing to allow the addition of lightweight fine aggregate to modify paving mixtures”. Flexural strength could be used “to determine when a concrete pavement can be placed in service”.

We conducted tests to establish a comparison of flexural strength with and without internal curing. A normal weight concrete and an identical mix with 100 lb (45 kg) replacement of lightweight aggregate sand were compared. The w/c ratio was .434, slump 1 ¾” to 2”, air content 5 to 6 % and identical admixtures were used. The flexural strength improvement with IC at three (3) days was 15%; the IC flexural strength at 3 days was 75% of the 28-day strength value.

Visual #12

To achieve the optimum IC results there are certain obligatory lightweight aggregate characteristics needed for effective internal curing and hydration of the cement not otherwise hydrated. They are: uniform and properly expanded lightweight aggregates that have pores that permit rapid absorption and release of water, crushed to maximize the vesicular surface of the material, screened to approximate the size of the natural sand replaced, processed so that the particle shape is roughly cubical, and strong enough particles so that the strength of the normal weight material being replaced is not compromised.

The procedure to follow to obtain optimum IC is:

Visual #13

- Batch a known quantity of absorbed water with each cubic yard to obtain optimum internal curing,
- Replace natural aggregate sand with lightweight aggregate sand to maximize distribution of the absorbed water needed for more hydration,

Visual #14

- Use structural grade crushed lightweight aggregate sand to improve the mortar strength and minimize any differences in particle and concrete strength,
- Use sand size of lightweight aggregate for simplicity in mix design, material handling, moisture control and lower cost,

Visual #15

- Avoid lightweight coarse aggregate replacements, which don't have the approximate gradation of the natural aggregate being replaced,
- Provide moisture control during shipment, storage, and batching (SSD at batching).

Visual #16

To summarize, in 2004, improvements to concrete through IC in pavements, bridges and parking structures can be achieved. State-of-the-art concrete can be improved by the substitution of a structural grade crushed expanded shale sand for an equal volume of natural sand.

Visual #17

Internal Curing improvements in flexural strength, early-age strength, permeability, lower autogenous shrinking & cracking, compressive & tensile strength, durability and earlier use.

Visual #18

At a water/cement ratio of .434, use 100 lbs (45 kg) of lightweight aggregate sand; at lower w/c ratios, more will be needed. The investment in IC will give better concrete, quicker usage, improved protection of reinforcing steel and design flexibility.

INTERNAL CURING

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Internal Curing (IC) Makes Good Concrete Better

Improved Concrete Quality through IC

- Early-age (< 24 hrs.) Strength
- Compressive, Flexural, & Tensile Strengths
- Lower Autogenous Cracking
- Lower Permeability
- Increased Durability
- Earlier Use of the Concrete

Internal Curing

Hydration of Cement Particles
Deprived of Mixing Water
in
Low w/c Ratio Concretes
from
Water Provided by
a Source Such as
Lightweight Sand
Produced from
Structural Grade
Expanded Shale

First Chesapeake Bay Bridge 1952, second 1975, Proven Performance!

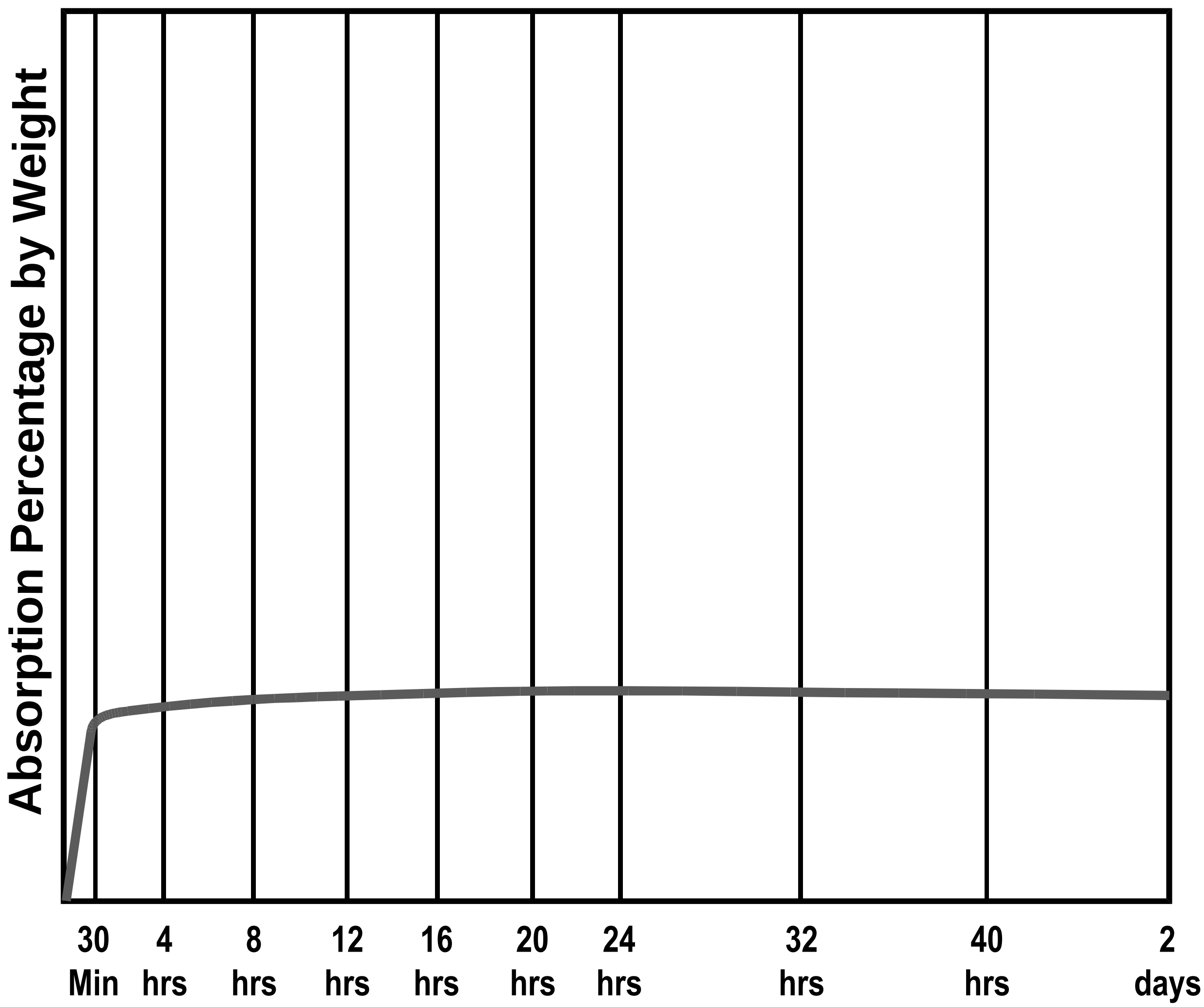
Deck of 1952 Bridge

Non Air-Entrained

Rehabilitated 1987

1952 NRMCA Lab Test Lightweight Aggregate Freeze-Thaw

Relationship
Time / Rate of Absorption



Quick Absorption
Means Early Water Release

Effect of Internal Curing Comparison of Absorption Characteristics of Normal Weight and Lightweight

Normal Weight LimestoneCoarse Aggregate, Absorption > 1%

- Survey of bridge decks free of autogenous cracking studied over 4 years by Dale Crowl and Mike Sutek, District 12 – Ohio DOT
- 1500 lb. (680 kg) stone coarse aggregate, w/c ratio: > 0.42
- Water Needed:
  1% x 1500 lb. (680 kg)
  = 15 lb. (6.8 kg)

Lightweight Aggregate (Expanded Shale), Absorption > 15%

- Tests conducted in 1999-2000 show improved strength, permeability, and durability compared to normal weight
- 100 lb. (45 kg) lightweight sand, w/c ratio = 0.434
- Water Needed:
  15% x 100 lb. (45 kg)
  = 15 lb. (6.8 kg)

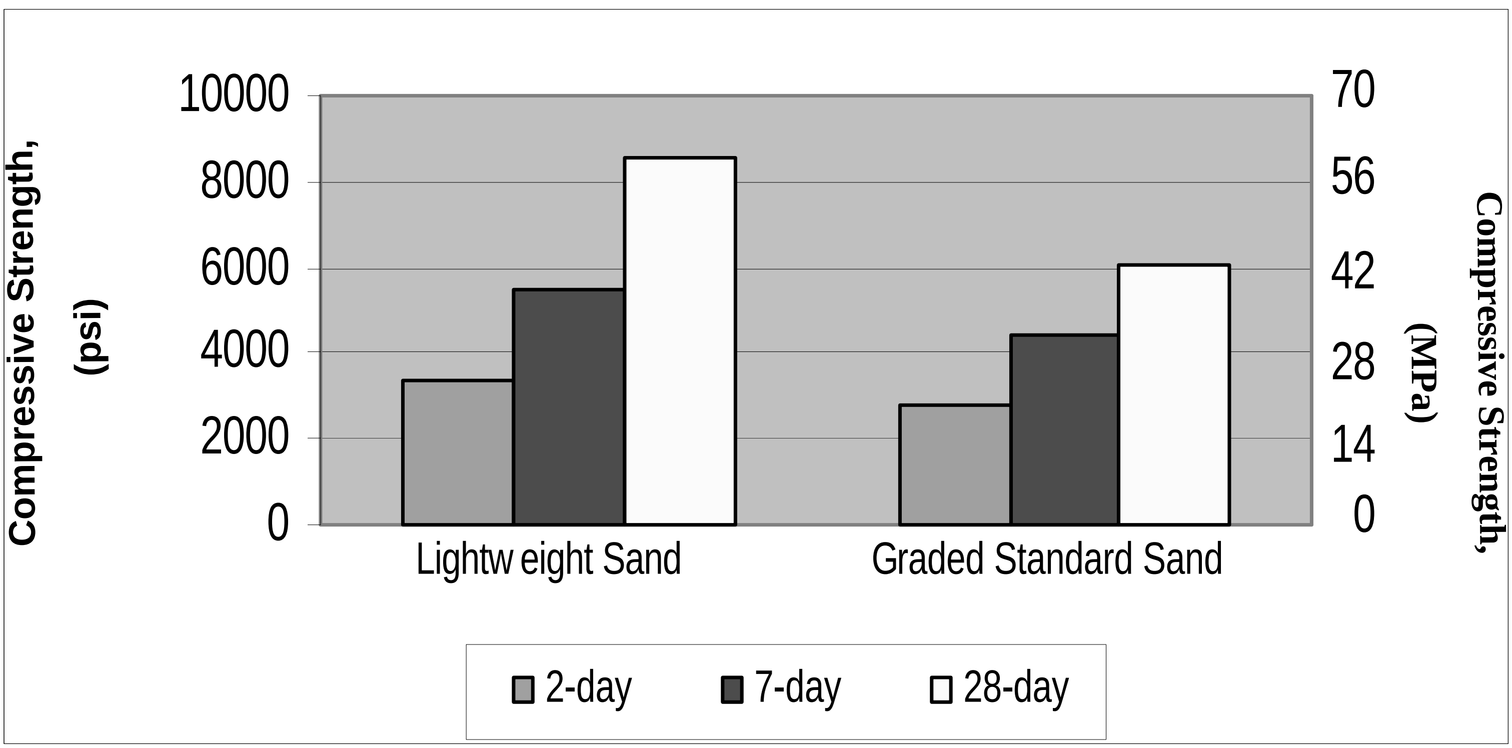
Improvement from the Replacement of Some of the Natural Sand with an Equal Volume of Lightweight Aggregate Sand

100 lbs (45 kg) of Lightweight Aggregate w/c .434

Parameter	% Improvement
84 Day Permeability (coulombs)	25
3 Day Flexural Strength	14
28 Day Compressive Strength	10
28 Day Tensile Strength	6
Durability Factor	2

Masonry Mortar Test
(ASTM C 109/C 109M-02)

Test	Compressive Strength, psi (MPa)	
	Hydrocure® Lightweight Aggregate	Standard Graded Sand
2-day ave.	3390 (23.4)	2790 (19.2)
7-day ave.	5500 (37.9)	4430 (30.6)
28-day ave.	8580 (59.2)	6050 (41.7)



To Make Mortar Stronger the Lightweight Aggregate Substituted Needs These Characteristics

- Particle Shape
- Particle Strength
- Gradation
- Absorption (SSD)
- Rheology

3-day Flexural Strength Improvement with IC

Flexural Strength		
	Without Internal Curing	With Internal Curing
	Natural Sand and Stone	Lightweight sand 100 lb replacement
w/c ratio	0.434	0.434
Slump	1 3/4" (44 mm)	2" (50 mm)
Air content	5 - 6%	5 - 6%
Admixtures	same	same

Test Age Days	Modulus of Rupture Average PSI (MPa)	Modulus of Rupture Average PSI (MPa)
3	582 (400)	675 (466)
7	755 (521)	782 (540)
28	855 (590)	890 (674)

Lightweight Aggregate Characteristics Needed for Effective Internal Curing

- Uniform and properly expanded lightweight aggregates that have pores that permit rapid absorption and release of water,
- Crushed to maximize the vesicular surface of the material,
- Screened to approximate the size of the natural sand replaced,
- Processed so that the particle shape is roughly cubical.
- Strong enough particles so that the strength of the normal weight material being replaced is not compromised.

Internal Curing Procedure

Batch a known quantity of absorbed water with each cubic yard to obtain Optimum Internal Curing

Replace Natural Aggregate Sand with Lightweight Aggregate Sand to Maximize Distribution of *the Absorbed Water* Needed for More Hydration.

Internal Curing Procedure *(cont'd)*

Use Structural Grade Crushed Lightweight Aggregate Sand Size to improve the mortar strength and Minimize Any Differences in Particle and Concrete Strength

Use Sand Size of Lightweight Aggregate for Simplicity in:

- **Mix Design**
- **Material Handling**
- **Moisture Control**
- **Lower Cost**

Internal Curing Procedure *(cont'd)*

Avoid Lightweight Coarse Aggregate Replacements Which Do Not Have the Approximate Gradation of the Natural Aggregate Being Replaced

Provide Moisture Control during Shipment, Storage and Batching

Summary

Low w/c Ratio Concrete

Can be ***Improved***

by
the **Substitution of a Structural Grade Crushed Expanded Shale** Sand
for
an ***Equal*** Volume of
Natural Sand.

Summary ***(cont'd)***

Internal Curing

Improvements

- **Flexural Strength**
- **Early-Age Strength**
- **Permeability**
- **Lower Autogenous Shrinking & Cracking**
- **Compressive & Tensile Strength**
- **Durability**
- **Earlier Use**

Summary *(cont'd)*

At a Water / Cement Ratio of .434, Use 100 lbs (45 kg) of Lightweight Aggregate; At Lower w/c Ratios, More will be Needed.

The Investment in IC will give:

- **Better Concrete**
- **Quicker Usage**
- **Improved Protection of reinforcing Steel**
- **Design Flexibility**