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Internal Curing

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Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. The December 2015 MAP Brief provides information relevant to Track 8 of the CP Road Map: Materials and Mixes for Concrete Pavements.

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"Moving Advancements into Practice"

MAP Brief December 2015

Best practices and promising technologies that can be used now to enhance concrete paving

Internal Curing

Introduction

For the last two decades, the concept of internal curing has been a subject of laboratory research (1, 2, 3, 4, 5, 6, 7). Recently, however, internal curing has made the transition from the laboratory to field trials and finally to field implementation. The use of internal curing to date has primarily been in bridge decks in Illinois, Indiana (8), New York (9), and Utah (10); pavement patches in Indiana, Texas, and Michigan; and pavements in Kansas. Additional states are also actively experimenting with the use of internal curing for pavements, overlays, and bridge decks. This MAP Brief discusses the primary concepts behind internal curing, describes tools for use in mixture proportioning and quality control, and discusses potential concrete pavement applications.

Internal curing concept

Curing is vital for hydraulic cement concretes to hydrate, gain strength and provide durability (11, 12). When the internal relative humidity (relative pore pressure or water activity) decreases the rate of reaction slows and may even cease (13). It has long been known that supplying additional water after the concrete has set can improve the overall performance of the concrete by increasing the reaction of the cementitious materials. With conventional concrete, this is typically done by supplying water from the outside (wetting the surface). Internal curing provides a modern twist on this practice by supplying curing water from within the concrete, increasing the reaction of the cementitious materials (Figure 1). Figure 1 shows that for conventional concrete the penetration of external water may be effective in conventional mixtures; however, the depth that the external water can penetrate can be limited for lower water-to-cementitious ratio, higher strength concrete. Internal curing uses water filled inclusions to better disperse the curing water throughout the depth of the concrete. In North America, this water filled inclusion is typically an expanded lightweight aggregate.

Internal curing will reduce autogenous shrinkage and cracking in concrete (13), reduce plastic shrinkage cracking (14), and increase the extent of the hydration reaction that reduces fluid transport (15). Internal curing can also reduce damage associated with ASR due to dilution, providing space to accommodate ASR gel and altering pore solution composition (16) while providing similar strength (17) and freeze-thaw (18) performance.

Figure 2 provides an example to demonstrate the similarities and differences between the design of a conventional 6-bag mixture (water-to-cement ratio of 0.36 and 6% air) and an internally cured mixture using the same volume proportions of the constituents. First, it should be noted that with the exception of fine aggregate and fine lightweight aggregate, the remainder of the internally cured concrete mixture design is identical to that of the conventional concrete with similar air, water, and coarse-aggregate content. Internal curing in North America is typically achieved by

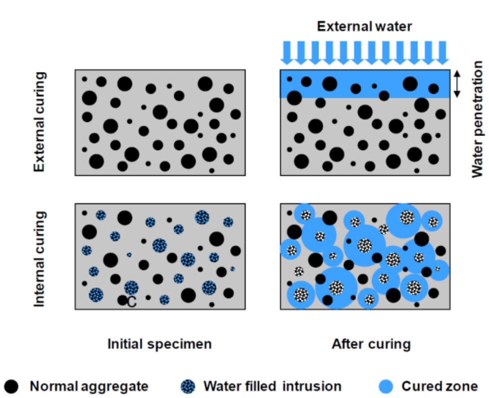

Figure 1. Illustration of conventional curing as compared with internal curing

replacing a portion of the conventional fine aggregate (i.e., sand) with a prewetted lightweight fine aggregate (LWA). The volume of sand replaced may vary depending upon porosity and desorption of the lightweight fine aggregate.

The example in Figure 2 considers an aggregate with approximately 20% absorption that is intended to provide a volume of internal curing water equivalent to the volume of chemical shrinkage of a typical cement. This corresponds to replacing approximately 30% of the volume of the fine aggregate (approximately 460 lb/yd^3) for this mixture with a fine lightweight aggregate. The specific details of the mixture design will vary depending on the properties (specific gravity and porosity) of the local materials.

The following section describes how these calculations can be done for a specific mixture. It should be noted that although either the coarse or fine aggregate can be replaced with LWA to provide internal curing the fine aggregate is frequently selected to provide the best distribution of the internal curing water throughout the matrix.

Mixture Proportioning

While the concept of designing a concrete mixture from scratch may sound daunting, converting a conventional concrete mixture to an internally cured mixture is relatively straightforward. The first paragraph of this section describes the principles used for converting a conventional mixture design to an internally cured mixture design and the second paragraph presents a tool to perform this calculation automatically. It should be noted that this spreadsheet is one approach and there are other approaches that can be used to design internally cured mixtures.

The only change needed to convert a conventional concrete mixture to an internally cured concrete mixture is to replace a portion of the fine aggregate with the lightweight aggregate (19). To calculate the amount of LWA needed, a two-step process is used. First, the amount of water 'hidden' in the LWA to be used for internal curing is determined. This internal curing water is typically estimated as

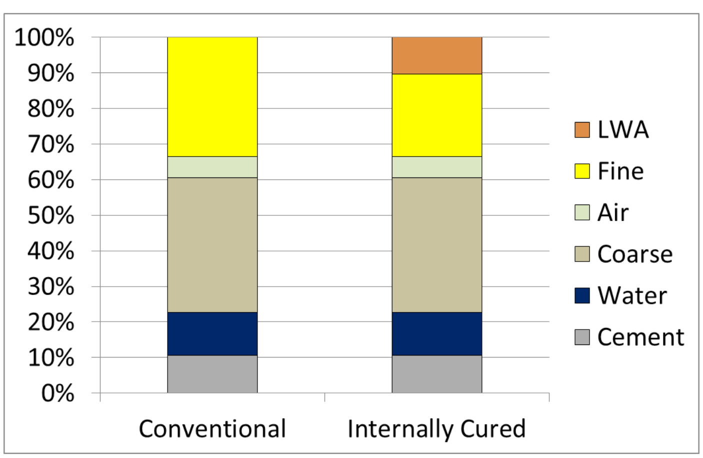

Figure 2. Conceptual illustration of volumetric components in a plain and internally cured mixture

7 lbs of water for every 100 lbs of cementitious materials used in the mixture. The example shown in Figure 3 has 610 lb/yd^3 of cementitious materials; therefore, 42.7 lb/yd^3 of internal curing water is needed.

Second, the amount of LWA required for this amount of internal curing water is determined based on the mass of the internal curing water and the absorption of the LWA (this can be adjusted to account for the fact that not all water will desorb from the aggregate; however, this is a secondary effect). Once the total volume and mass of lightweight aggregate are determined the volume (and mass) of the fine lightweight aggregate are adjusted so that the volume of LWA and fine aggregate in the internally cured mixture is equal to the volume of the fine aggregate in the original mixture. This process can be automated as described in the following paragraph.

To aide in the conversion of a conventional concrete mixture to an internally cured mixture a spreadsheet was developed (20,21) that is available online (22) (Figure 3). This spreadsheet performs the calculations that are discussed in the previous section if the user enters two types of information: 1) information from the original mixture design in the orange cells and 2) information on the LWA properties in the green cells. The information that is needed from the original mixture designs is the original air content, the mass of the original constituents and the specific gravity of the original constituents. As such this information is typically readily available.

Three pieces of information are needed to describe the properties of the lightweight aggregate: 1) the absorption of the LWA, 2) the desorption of the LWA and 3) the specific gravity of the LWA. While this information can be measured for a specific project following the procedures outlined in ASTM C1761, Table 1 provides information on North American fine lightweight aggregate made from expanded clay, shale, slate or slag that has been assembled from the literature to provide a first approximation of the values that can be used. The last three columns in Table 1 can be used in the green LWA cells (Cell C21, C22, C23) in Figure 3 to aide in proportioning internally cured concrete.

Operations

While internal curing mixtures can be designed using oven dry aggregate or pre-wetted lightweight aggregate, the pre-wetted lightweight aggregate is substantially easier to implement in many field applications (26). To condition the aggregate to a stable pre-wetted state, the pile of fine lightweight aggregate can be wetted using a sprinkler. The wetting of the pile with the sprinkler is generally applied for a period of 48 hours. Approximately 12 hours before the concrete is batched the sprinkler is turned off and the pile is permitted to drain down. Before the aggregate is added to the bins, the pile of LWA is typically rotated to obtain consistent aggregate moisture though the pile.

As with conventional concrete, daily mixture adjustments for aggregate moisture are essential for quality control and even more important when using lightweight aggregate. Two test methods could be used to determine the surface moisture of fine lightweight aggregate: a paper towel test and the centrifuge test. The paper towel test consists of dabbing a paper towel on the surface of LWA as it dries to determine whether moisture is picked up by the towel or not. When the paper towel no longer picks up moisture it is assumed that the LWA is surface dry and the difference in the mass between the original and surface dry condition can be used to determine the surface moisture.

	A	B	C	D	E	F
1	Project:			Date:		
2	Mixture ID:					
3	Operator:					
4		Plain Mixture Design			Legend	
5		Target Air, %	6.5%		Ready Mix Input	
6		w/c	0.421		LWA Input	
7						
8		Materials	Weight	SG (SSD)	Volume, ft^3	
9		Cement	455	3.15	2.315	
10		GGBFS	130	2.99	0.697	
11		Fly Ash	0	2.64	0.000	
12		Silica Fume	25	2.2	0.182	
13		Sand	1231	2.623	7.521	
14		Coarse Aggregate 1	1795	2.763	10.411	
15		Coarse Aggregate 2	0	2.763	0.000	
16		Water	257	1	4.119	
17		Air	0	0	1.755	
18		Σ	3893	-	26.999	
19						
20		Internal Curing Properties				
21		LWA Absorption:	15.0%	←This is 24 hour design absorption		
22		LWA Desorption:	85.0%	←If unknown, use 85%		
23		LWA PSD Specific Gravity	1.750	←This is 24 hour pre-wetted surface-dry		
24		Cement Factor	610	specific gravity for preliminary design		
25		Chemical Shrinkage:	0.07			
26		Degree of Hydration	1			
27		PSD LWA Replacement	385			
28		SSD Sand Replaced	577			
29		% Volume Replacement	46.9%			
30						
31		IC Mixture Design				
32		Materials	Weight	SG (SSD)	Volume, ft^3	
33		Cement	455	3.15	2.315	
34		GGBFS	130	2.99	0.697	
35		Fly Ash	0	2.64	0.000	
36		Silica Fume	25	2.2	0.182	
37		Sand	654	2.623	3.994	
38		Lightweight Aggregate	385	1.750	3.527	
39		Coarse Aggregate 1	1795	2.763	10.411	
40		Coarse Aggregate 2	0	2.763	0.000	
41		Water	257	1	4.119	
42		Air	0	0	1.755	
43		Σ	3701	-	26.999	

Figure 3. Screen capture of the spreadsheet used to convert a mixture to an internally cured mixture

Miller et al. (27) used a centrifuge procedure in which the LWA is spun in a centrifuge at 2,000 rpm for 3 minutes to remove surface moisture. By comparing the mass of the initial sample and sample after spinning the surface moisture can be determined. This can be done substantially faster and more accurately than using the paper towel method (27). A spreadsheet to perform this calculation is provided at (23).

Potential Applications

While the vast majority of field trials have focused on the use of internal curing for bridge decks, where internal curing has shown reduced cracking and long service life (6,29), the beneficial uses of internally cured concrete has potential in other applications as well. Figure 5 illustrates field trials performed in West Lafayette, Indiana in 2014 that used internal curing with expanded slag aggregate in high early strength concrete pavement patches. The application of internal curing in the high early strength patches provides a concrete with two distinct benefits when compared with conventional concrete: 1) reduced built-in stress caused by the restraint of shrinkage and 2) increased water curing after the patches are covered with curing compound and opened to traffic.

In addition to the use of internal curing in patches, research is underway to evaluate the potential for using internal curing in continuously reinforced concrete pavement (CRCP). It has been shown that internal curing could result in thinner CRCP, provided the internal curing can reduce the built-in stress associated with moisture gradients (30). Using similar reasoning, there is a great interest in investigating the potential use of internal curing for white topping and ultra-thin white topping as a way to reduce built-in stress caused by restrained shrinkage. If internally cured mixtures reduce curling and built-in stress as estimated (30), there may be even more benefits of using internal curing. Research would be needed to determine if the same benefits could be obtained for jointed plain concrete pavement (JPCP). Research is currently being performed to determine the influence of internal curing on curling and built in curling stress (31).

Table 1. Expanded LWA properties for North American lightweight aggregate (*23 , ^24 , &25)

Material Type	Production Location	Vacuum Water Absorption*	Specific Gravity, Oven Dry*	24 Hour Water Absorption^	24 Hour Desorption^	Specific Gravity, 24 Hour Calc.
Clay	Erwinville, LA	26.8%	1.29	16.4%	92.4%	1.50
Clay	Germany	27.0%	1.49	15.0%*	93.6%*	1.71
Clay	Livingston, AL	35.5%	1.10	30.0%	97.5%	1.43
Clay	Frazier Park, CA	19.1%	1.39	17.5%	95.2%	1.63
Shale	Marquette, KS	22.5%	1.45	18.8%	96.2%	1.72
Shale	New Market, MO	24.9%	1.50	14.9%	98.3%	1.72
Shale	Brooklyn, IN	20.0%	1.56	12.4%	97.5%	1.75
Shale	Cleveland, OH	18.6%	1.40	17.1%	97.3%	1.64
Shale	Brooks, KY	22.0%	1.51	17.3%	96.4%	1.77
Shale	Albany, NY	25.2%	1.38	17.4%	95.7%	1.62
Shale	Boulder, CO	24.9%	1.46	19.0%	89.8%	1.74
Shale	Streetman, TX	24.6%	1.48	20.1%	88.0%	1.78
Shale	Coalville, UT	23.0%	1.49	19.7%	90.6%	1.78
Slate	Buckingham, VA	18.6%	1.62	16.4%	97.1%	1.89
Slate	Gold Hill, NC	11.4%	1.51	9.1%	97.5%	1.65
Slag	Chicago, IL	~	2.00&	10.5%	92.6%	2.21

Figure 4. Illustration of the centrifuge, which has been used to determine the moisture properties of fine LWA

Figure 5. Example of internally cured concrete being used for concrete pavement patching

Summary

Internal curing has been the subject of many laboratory investigations over the last two decades. Internally cured concrete has been successfully used in full scale bridge decks and concrete pavement patching projects. Field trials are underway to examine the potential use of internally cured concrete in CRCP (continuously reinforced concrete pavement), white topping, UTW (ultra-thin white topping), and JPCP (jointed plain concrete pavements). This article has outlined how internally cured concrete mixtures can be designed using the mixture proportions of conventional concrete (Figure 3) with properties of fine lightweight aggregate (Table 1). Field experience has shown that, in general, internally cured concrete has similar workability, similar strength and mechanical property development, reduced stress development and cracking, and improved durability when compared with conventional concrete.

References

1. RILEM 196-ICC Internal Curing of Concrete - State-of-the-Art Report of RILEM Technical Committee 196-ICC Edited by K. Kovler and O. M. Jensen ISBN: 978-2-35158-009-7

2. BENTZ, D. P. & WEISS, W. J. 2011. Internal Curing: A 2010 state of the art review. Gaithersburg, MD: National Institute of Standards and Technology, U.S. Department of Commerce.

3. http://ciks.cbt.nist.gov/~bentz/phpct/database/ic.html

4. RADLINSKA, A., RAJABIPOUR, F., BUCHER, B., HENKENSIEFKEN, R., SANT, G. & WEISS, J. 2008. Shrinkage mitigation strategies in cementitious systems: A closer look at differences in sealed and unsealed behavior. Transportation Research Record: Journal of the Transportation Research Board, 2070, 59-67

5. DI BELLA, C., SCHLITTER, J., CARBONEAU, N. & WEISS, J. 2012. Documenting the Construction of a Plain Concrete Bridge Deck and an Internally Cured Bridge Deck. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University.

6. CUSSON, D. & HOOGEVEEN, T. 2008. Internal curing of high-performance concrete with pre-soaked fine lightweight aggregate for prevention of autogenous shrinkage cracking. Cement and Concrete Research, 38, 757-65.

7. ACI 231-R10 Report on Early-Age Cracking: Causes, Measurement, and Mitigation

8. BARRETT, T., MILLER, A. E., and WEISS, W. J., (2015) "Documentation of Bridge Deck Construction Using Industrially Produced, Internally Cured, High Performance Concrete," Australia 2015

9. STREETER, D. A., WOLFE, W. H., and VAUGHN, R. E., 2013 "Field Performance of Internally Cured Concrete Bridge Decks in New York State, ACI SP 290

10. GUTHRIE, W. S. and STEVENS, D., 2013 "internal Curing of Concrete Bridge Decks in Utah: Preliminary Evaluation"

11. MINDESS, S., YOUNG, J. F. & DARWIN, D. 2003. Concrete, Upper Saddle River, Prentice Hall.

12. TAYLOR, P., Curing Concrete, CRC Press, 2014

13. HENKENSIEFKEN, R., BENTZ, D., NANTUNG, T. & WEISS, J. 2009. Volume change and cracking in internally cured mixtures made with saturated lightweight aggregate under sealed and unsealed conditions. Cement and Concrete Composites, 31, 427-437.

14. HENKENSIEFKEN, R, BRIATKA, P., BENTZ, D. P., NANTUNG, T. E., and WEISS, W. J., (2009), "Plastic Shrinkage Cracking in Internally Cured Mixtures made with Prewetted Lightweight Aggregate", Concrete International, Vol 32/2, p. 49-54

15. CASTRO, J., SPRAGG, R., and WEISS, W. J., (2011) "Internal Curing for W/C Systems Between 0.30 and 0.45: Impact on Water Absorption and Electrical Conductivity," ASCE Journal of Civil Engineering Materials, Vol. 24/2, p. 223-231, doi: 10.1061/(ASCE)MT.1943-5533.0000377

16. SHIN, K., CASTRO, J., SCHLITTER, J., GOLIAS, M., POUR-GHAZ, M., HENKENSIEFKEN, R., PELED, A., and WEISS, (2010) "Chapter 9: The Role of Internal Curing as a Method to Improve Durability," Handbook on Concrete Durability, Ed S H Kim and K Y Ann, Middelton Publishing, p 379-428

17. GOLIAS, M., BENTZ, D., and WEISS, (2014) "Influence of Sample Curing Conditions on Internal Curing Benefits Seen in Cementitious Materials," 09/2014; 2(1):12. DOI:10.1520/ACEM20120023

18. JONES, W. A., and WEISS, W. J., 2015 "Freezing and Thawing Behavior of Internally Cured Concrete," ASTM - Advances in Civil Engineering Materials, 05/2015; 4(1):20140044. DOI:10.1520/ACEM20140044

19. BENTZ, D. P., LURA, P. & ROBERTS, J. W. 2005. Mixture proportioning for internal curing. Concrete International, 27, 35-40

20. MILLER, A. E., 2015 "Using a Centrifuge for Quality Control of Pre-Wetted Lightweight Aggregate in Internally Cured Concrete," MSCE Purdue University

21. BARRETT, T. J., MILLER, A., and WEISS, W. J., 2015 "SPR 3752 – Documentation of the INDOT Experience and Construction of Bridge Decks Containing Internal Curing in 2013).

22. http://cce.oregonstate.edu/internalcuring

23. CASTRO J., KEISER, L., GOLIAS, M., and WEISS, W. J., (2011) "Absorption and Desorption of Fine Lightweight Aggregate for Applications to Internally Cured Concrete Mixtures" Cement and Concrete Composites, Vol. 33/10, p. 1001-1008

24. MILLER, A. E., BARRETT, T. J., ZANDER, A. R. & WEISS, W. J. 2014b. Using a Centrifuge to Determine Moisture Properties of Lightweight Fine Aggregate for Use in Internal Curing. Advances in Civil Engineering Materials, 3.

25. HOUSE, M., DIBELLA, C., SUN, H., ZIMA, G., BARCELO, L. & WEISS, W. J. 2014. The influence of slag aggregate production on its potential for use in internal curing. Transportation Research Record

26. CASTRO, J., SPRAGG, R., and WEISS, W. J., (2011) "Internal Curing for W/C Systems Between 0.30 and 0.45: Impact on Water Absorption and Electrical Conductivity," ASCE Journal of Civil Engineering Materials, Vol. 24/2, p. 223-231, doi: 10.1061/(ASCE)MT.1943-5533.0000377

27. MILLER, A. E., BARRETT, T. J., ZANDER, A. R. & WEISS, W. J. 2014b. Using a Centrifuge to Determine Moisture Properties of Lightweight Fine Aggregate for Use in Internal Curing. Advances in Civil Engineering Materials, 3.

28. MILLER, A., SPRAGG, R., ANTICO, F. C., ASHRAF, W., BARRETT, T., BEHNOOD, A., BU, Y., CHIU, Y., DESTA, B., FARNAM, Y., JEONG, H., JONES, W., LUCERO, C., LUO, D., NICKEL, C., PANCHMATIA, P., PIN, K., QIANG, S., QIAO, C., SHAGERDI, H., TOKPATAYEVA, R., VILLANI, C., WIESE, A., WOODARD, S., WEISS, W. J., MACOBATTI, F. & TIAN, Q. Determining the moisture content of prewetted lightweight aggregate: Assessing the variability of the paper towel and centrifuge methods. 4th International Conference on the Durability of Concrete Structures, ICDCS 2014, July 24, 2014 - July 26, 2014, 2014a West Lafayette, IN, United states. Purdue University, 312-316.

29. WEISS, J., BU, Y., DI BELLA, C. & VILLANI, C. 2014. Estimated performance of as-built internally cured concrete bridge decks and thoughts on performance related specifications. RILEM International workshop on performance-based specification and control of concrete durability. Zagreb, Croatia.

30. RAO, C., and DARTER, M. I., 2013 "Evaluation of Internally Cured Concrete For Paving Applications," Report

31. ROESSLER, J., ZOLLINGER, D., and WEISS (2014) "Innovative Structural and Material Design of Continuously Reinforced Concrete Pavement (CRCP)" Illinois Tollway