

# Guide Specification for Internally Curing Concrete

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<b>16. Abstract</b> Internal curing (IC) is a practical way of supplying additional curing water throughout the concrete mixture. This water can improve the hydration of cement, reduce autogenous shrinkage, and improve durability. The purpose of this document is to provide guidance for the development of project specifications for internally cured concrete projects. The guidance in this document is designed to supplement the agency's standard specifications for concrete pavement. If the standard specifications are outdated, modifications other than those provided in this document may be necessary to produce a high-quality, long-lasting concrete. This document contains IC specification language, references to IC resources, references to IC instructional videos, and references to tools that can be used for IC of concrete or providing quality control.		<b>13. Type of Report and Period Covered</b> Guide Specification	
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# Guide Specification for Internally Curing Concrete

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## Appendix Acknowledgment

The Appendix of this document was originally published, before editing, as part of the following:

Montanari, L. 2017. Toward a Mixture Design Methodology for Internally Cured Concrete that Considers Filling Specific Pore Sizes Caused by Self-Desiccation. MS thesis. Oregon State University, Corvallis, OR.

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# I. INTRODUCTION

Although the concept of internal curing (IC) was discussed for use in higher performance concrete by Philleo nearly four decades ago, it wasn't until the late 1990s that research papers on IC began appearing in earnest. The early research on IC concrete focused on low water-to-cementitious (w/cm) ratio concrete. Over time, however, benefits have been observed when IC has been used in a wider range of mixtures. Recently IC has begun to make a transition from laboratory research to field trials and use in daily construction and contracts. Applications for IC to date have primarily been researched for use in bridge decks in Colorado, Illinois, Indiana, Louisiana, New York, Ohio, Oregon, and Utah. Kansas and the Illinois Tollway have begun to experiment with the use of IC for paving, whereas patching mixtures have been investigated in Indiana and Michigan. Experimental testing is also under way to evaluate IC for use in concrete overlays (white topping).

This document includes a Technical Brief on Internal Curing that discusses the primary concepts behind IC, describes tools for use in mixture proportioning and quality control, and discusses potential concrete pavement applications. The brief also includes a section outlining additional reference materials that are provided for further study. The primary goal of this document, however, is to provide guidance for the development of project specifications that include internally cured concrete. The guidance in this document is based on the agency's standard specifications for concrete. If the standard specifications are outdated or rarely used, modifications other than those provided in this document (e.g., aggregate grading, w/cm ratio less than 0.42, permeability, smoothness incentives, etc.) may be necessary to produce a high-quality, long-lasting concrete pavement.

Following are links to sample specifications:

Expanded Shale Clay and Slate Institute (ESCSI)—<http://utelite.net/File/c138b178-dded-48e0-934e-bd7fa1b3883d>

New York State DOT (NYSDOT)—<https://www.dot.ny.gov/spec-repository-us/557.63010108.pdf>

Indiana DOT (INDOT)—[http://www.in.gov/indot/div/mt/itm/pubs/222\\_testing.pdf](http://www.in.gov/indot/div/mt/itm/pubs/222_testing.pdf)

Illinois Tollway—contact Steve Gillen [sgillen@getipass.com](mailto:sgillen@getipass.com)

Montanari, L. 2017. Toward a Mixture Design Methodology for Internally Cured Concrete that Considers Filling Specific Pore Sizes Caused by Self-Desiccation. MS thesis, Oregon State University, Corvallis, OR. <http://hdl.handle.net/1957/61719>

The Appendix of this guide specification includes a potential test method that can be utilized for assessing the absorption capacity of superabsorbent polymers (SAPs). It was originally published, before editing, as part of Luca Montanari's MS thesis listed above.

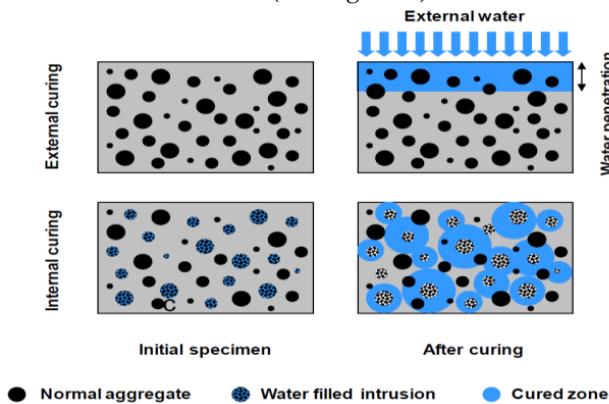
# II. INTERNAL CURING CP MAP BRIEF – 2017

## Introduction

For the last two decades, the concept of internal curing has been a subject of laboratory research (1, 2, 3, 4, 5, 6). 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 (7), New York (8), and Utah (9); 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 (10, 11). When the internal relative humidity (relative pore pressure or water activity) decreases, the rate of reaction slows and may even cease (12). 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 (see Figure 1).



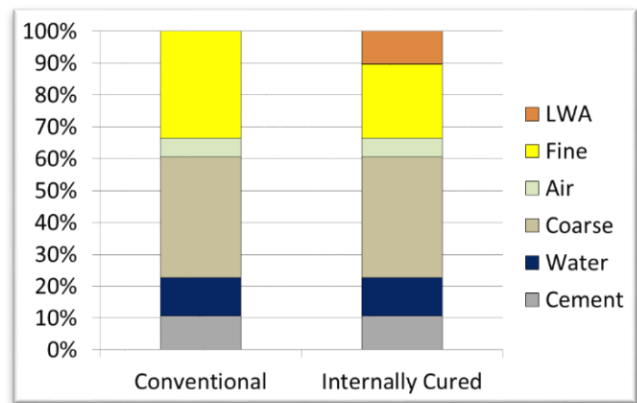
**Figure 1. Conventional curing compared to internal curing**

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 (w/cm) 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 (LWA).

Internal curing will reduce autogenous shrinkage and cracking in concrete (12), reduce plastic shrinkage cracking (13), and increase the extent of the hydration reaction that reduces fluid transport (14). Internal curing can also reduce damage associated with alkali-silica reaction (ASR) due to dilution, providing space to accommodate ASR gel and altering pore solution composition (15), while providing similar strength (16) and freeze-thaw performance (17).

Figure 2 provides an example to demonstrate the similarities and differences between the design of a conventional 6-bag mixture (w/cm ratio of 0.36 and 6% air) and an internally cured mixture using the same volume proportions of the constituents.



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

First, it should be noted that with the exception of fine aggregate and lightweight fine aggregate (LWFA), 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 replacing a portion of the conventional fine aggregate (i.e., sand) with a prewetted LWFA. The volume of sand replaced may vary depending upon porosity and desorption of the LWFA.

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<sup>3</sup>) for this mixture with a LWFA.

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 LWFA 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 LWFA (18). To calculate the amount of LWFA needed, a two-step process is used. First, the amount of water “hidden” in the LWFA to be used for internal curing is determined. This internal curing water is typically estimated as 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<sup>3</sup> of cementitious materials; therefore, 42.7 lb/yd<sup>3</sup> of internal curing water is needed.

Second, the amount of LWFA required for this amount of internal curing water is determined based on the mass of the internal curing water and the absorption of the LWFA (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 LWFA are determined, the volume (and mass) of the LWFA are adjusted so that the volume of LWFA 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 aid in the conversion of a conventional concrete mixture to an internally cured mixture a spreadsheet was developed (19, 20) that is available online (21) (see Figure 3).

	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		<b>Materials</b>	<b>Weight</b>	<b>SG (SSD)</b>	<b>Volume, ft<sup>3</sup></b>	
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		<b>Σ</b>	<b>3893</b>	<b>-</b>	<b>26.999</b>	
19						
20		<b>Internal Curing Properties</b>				
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 specific gravity for preliminary design		
24		Cement Factor	610			
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		<b>IC Mixture Design</b>				
32		<b>Materials</b>	<b>Weight</b>	<b>SG (SSD)</b>	<b>Volume, ft<sup>3</sup></b>	
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		<b>Σ</b>	<b>3701</b>	<b>-</b>	<b>26.999</b>	
44						

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

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 LWFA 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 LWFA: the absorption, desorption, and specific gravity of the LWFA. While this information can be measured for a specific project following the procedures outlined in ASTM C1761, Table 1 provides information on North American LWFA 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.

**Table 1. Expanded LWA properties for North American lightweight aggregate**

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

Sources: \*22, ^23, and 24

The last three columns in Table 1 can be used in the green LWFA cells (Cell C21, C22, C23) in Figure 3 to aid in proportioning internally cured concrete.

## Operations

While internal curing mixtures can be designed using oven dried aggregate or prewetted LWFA, the prewetted LWFA is substantially easier to implement in many field applications (14). To condition the aggregate to a stable prewetted state, the pile of LWFA 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 LWFA is typically rotated to obtain consistent aggregate moisture throughout the pile.

As with conventional concrete, daily mixture adjustments for aggregate moisture are essential for quality control and even more important when using LWFA. Two test methods could be used to determine the surface moisture of LWFA: a paper towel test and the centrifuge test. The paper towel test consists of dabbing a paper towel on the surface of the LWFA 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 LWFA is surface dry and the difference in the mass between the original and surface dry condition can be used to determine the surface moisture.

Miller et al. (23, 25) used a centrifuge procedure in which the LWFA is spun in a centrifuge at 2,000 rpm for 3 minutes to remove surface moisture (see Figure 4). 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 (25).



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

A spreadsheet to perform this calculation is available (21).

## 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 (5, 26), 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.



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

The application of internal curing in the high early-strength patches provides a concrete with two distinct benefits when compared with conventional concrete: reduced built-in stress caused by the restraint of shrinkage and 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 (27). Using similar reasoning, there is a great interest in investigating the potential use of internal curing

for whitetopping and ultra-thin whitetopping (UTW) as a way to reduce built-in stress caused by restrained shrinkage. If internally cured mixtures reduce curling and built-in stress as estimated (27), 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 (28).

## 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, white topping, UTW, and JPCP. This brief has outlined how internally cured concrete mixtures can be designed using the mixture proportions of conventional concrete (Figure 3) with properties of LWFA (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.

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# III. GUIDE SPECIFICATION FOR INTERNALLY CURING CONCRETE

## A. HOW TO USE THE GUIDE

This guide specification, as with all specifications, is written to the contractor. The engineer provides specific requirements through the specifications for the contractor to complete the project. The following guide specifications for internally cured concrete are written for a public agency to use in the development of internally cured concrete and in developing supplemental specifications or special provisions to their own concrete pavement. It should be remembered that special provisions are a critical component of specifications. Prior to compiling their bids, contractors check the special provisions for each contract and also any supplemental specifications that the contracting authority may have that modify the standard specifications. These documents supersede the standard specifications and take precedence as the work is pursued.

These guide specifications were developed with the involvement of engineers and construction industry representatives from across the nation. They elected to identify aspects of typical concrete, and those items that are common to all concrete were identified and followed by the statement "Comply with contract documents." Those items specific to internally cured concrete only were also identified followed by the specification statement. In this way, the user of the guide specifications can continually refer to the entire listing of concrete items without having to go back to their own specifications in order to obtain an understanding of how IC-related items fit within the spectrum of concrete specifications.

The guide specification was developed based on the format used in AASHTO PP 84-17, and it provides additional information for the person using this guide to be able to develop a specification for a contract as footnotes at the bottoms of the pages.

This document was developed in good faith and its use in contract development as well as construction must be approved by the engineer who will assume any and all liability associated with its use. The appendix includes special provisions used by the New York State Department of Transportation (NYSDOT), the Indiana DOT (INDOT), and the Illinois Tollway. It also includes a provisional test for determining the absorption of superabsorbent polymers.

## B. ADDITIONAL IC RESOURCES

The following documents are recommended for obtaining in-depth guidance on the design and performance of internally cured concrete.

### **Internal Curing of Concrete—State-of-the-Art Report of RILEM Technical Committee 196-ICC**

This report discusses ongoing research into IC that is being intensively studied in research groups in several countries. The report presents knowledge about the principles, technologies, and effects of IC of concrete. The report discusses

mechanisms of internal water curing, the materials used for IC, and the impact of IC on concrete properties. Finally the future of IC is discussed.

Kovler, K. and O. M. Jensen, Eds. 2007. *Report 41: Internal Curing of Concrete - State-of-the-Art Report of RILEM Technical Committee 196-ICC*. RILEM Publications.

### **Internal Curing of High Performance Concrete: Lab and Field Experiences (ACI-SP 256)**

The document contains papers presented at the fall 2007 American Concrete Institute Convention about laboratory research, case studies, and practical applications related to IC of high-performance concretes.

Mohr, B. J. and D. P. Bentz, Eds. 2008. *Internal Curing of High Performance Concretes - Laboratory and Field Experiences*. ACI SP-256, American Concrete Institute, Farmington Hills, MI, CD-ROM. 9780870313066.

### **Internal Curing: A 2010 State-of-the-Art Review**

This report provides a state-of-the-art review of the subject of IC, first addressing its history and theory and then proceeding to summarize published guidance on implementing IC in practice and published research on its influence on the performance properties of concrete. The extension of the IC concept that employs the internal reservoirs to contain materials other than water is reviewed. Finally, the critical issue of sustainability is addressed. The report is mainly focused on the utilization of prewetted LWAs as the internal reservoirs because of this being the current established practice within the United States.

Bentz, D. P. and J. Weiss. 2011. *Internal Curing: A 2010 State-of-the-Art Review*. NIST Interagency/Internal Report (NISTIR) - 7765, National Institute of Standards and Technology, U.S. Department of Commerce.  
<https://concrete.nist.gov/~bentz/NISTIR7765.pdf>.

### **Development of Internally Cured Concrete for Increased Service Life**

This report provides an overview of the concept of IC using lightweight aggregates (LWAs). It is important the IC agent (LWA in this case) be able to provide a sufficient volume of water, have a structure that allows the water to be released to the paste as needed, and be small enough so that it can be appropriately spaced in the matrix. Local materials were used to internally cure concrete. Before concrete could be prepared, the locally produced LWA was characterized to determine absorption and desorption properties. Concrete mixtures were prepared for concrete with and without IC, and tests were performed to determine the autogenous shrinkage, drying shrinkage, plastic shrinkage cracking, drying shrinkage cracking, autogenous shrinkage cracking, water absorption, compressive strength, elastic modulus, tensile strength, thermal cracking, and freeze-thaw resistance. Internally cured mixtures were less likely to crack due to plastic, autogenous, and drying effects. Internal curing allowed a greater temperature swing in the concrete before cracking would occur.

Schlitter, J., R. Henkensiefken, J. Castro, K. Raoufi, and J. Weiss. 2010. *Development of Internally Cured Concrete for Increased Service Life*. Indiana



Department of Transportation and Purdue University Joint Transportation Research Program, West Lafayette, IN. <https://doi.org/10.5703/1288284314262>.

### **The Economics, Performance, and Sustainability of Internally Cured Concrete (ACI-SP 290)**

This document contains papers presented at the fall 2012 convention covering the following topics associated with IC: impact on sustainability, mixture proportioning, IC methods and their implementation, hydration impacts, volume change effects, mechanical properties, cracking tendency, durability aspects, life-cycle cost analysis, and case studies that document the use of IC in full-scale production applications.

Schlinder, A. K., J. G. Grygar, and W. J. Weiss, Eds. 2012. *The Economics, Performance, and Sustainability of Internally Cured Concrete*. ACI SP-290, American Concrete Institute, Farmington Hills, MI, CD-ROM. 9780870317835.

### **Application of Superabsorbent Polymers (SAPs) in Concrete Construction**

This report provides a summary of the use of SAPs in concrete construction. It begins with discussions of SAPs and their absorption and desorption properties. It then discusses the impact of SAPs on fresh concrete, volume change, mechanical properties, and durability. It describes potential applications and case studies.

Mechtcherine, V. and H. W. Reinhardt, Eds. 2012. *Application of Superabsorbent Polymers (SAP) in Concrete Construction - State-of-the-Art Report Prepared by Technical Committee 225-SAP*. Springer. Unedited version available at [https://www.rilem.net/global/gene/link.php?doc\\_id=3497&fg=1](https://www.rilem.net/global/gene/link.php?doc_id=3497&fg=1).

### **Evaluation of Internally Cured Concrete for Paving Applications**

This report evaluates the use of internally cured concrete for concrete pavement design and construction. Two key benefits of internally cured concrete are identified for use in pavements: (1) structural longevity (due to a reduction in unit weight, elastic modulus, coefficient of thermal expansion, and a small increase in strength), and (2) durability.

A positive impact was reported for internally cured concrete with respect to slab fatigue damage and associated slab cracking. When used in continuously reinforced concrete pavements, it was reported that the use of IC would lead to tighter crack openings and reduced punch-out failures. Several case studies were analyzed, and the results indicate improved performance, longer lives, and lower life-cycle cost for internally cured concrete as compared to conventional concrete. A survey of the literature was performed to state that also provides durability benefits through moisture-loss control and improved hydration, including that of supplementary cementitious materials (SCMs) from extended moisture supply.

An additional potential benefit was reported in the reduction in upward slab curling, which resulted in less detrimental effects of long-term drying shrinkage.

Rao, C. and M. I. Darter. *Evaluation of Internally Cured Concrete for Paving Applications*. Applied Research Associates, Inc., Champaign, IL, 2013. [http://www.escsi.org/uploadedFiles/Technical\\_Docs/Internal\\_Curing/Eval%20of%20ICC%20for%20Paving%20Apps%20Report.pdf](http://www.escsi.org/uploadedFiles/Technical_Docs/Internal_Curing/Eval%20of%20ICC%20for%20Paving%20Apps%20Report.pdf).

### **Report on Internally Cured Concrete Using Prewetted Absorptive Lightweight Aggregate (ACI 308-213, R-13)**

This report discusses the concepts of IC, the benefit of IC, and applications of IC. The report also describes mixture proportioning and absorptive material selection and discusses the benefits relating to sustainability.

ACI Committees 308, 213. 2013. *Report on Internally Cured Concrete Using Prewetted Absorptive Lightweight Aggregate*. ACI (308-213)R-13. American Concrete Institute, Farmington Hills, MI. 9780870318214.

### **Documentation of the INDOT Experience and Construction of the Bridge Decks Containing Internal Curing in 2013**

This document describes the experience of the INDOT in the construction of four bridge decks utilizing internally cured, high-performance concrete (IC HPC) during the summer of 2013. This report contains documentation of the production and construction of IC HPC concrete for the four bridge decks in this study. In addition, samples of the IC HPC used in construction were compared with a reference HPC that did not utilize IC. The mechanical properties of the IC HPC were tested, including resistance to chloride migration, potential for shrinkage and cracking was assessed, and the service life of the bridge decks was estimated. Collectively, the results indicate that the IC HPC mixtures that were produced as a part of this study exhibit the potential to more than triple the service life of the typical bridge deck in Indiana while reducing the early age autogenous shrinkage by more than 80% compared to noninternally cured concretes.

Barrett, T. J., A. E. Miller, and W. J. Weiss. 2015. *Documentation of the INDOT Experience and Construction of the Bridge Decks Containing Internal Curing in 2013*. Indiana Department of Transportation and Purdue University Joint Transportation Research Program, West Lafayette, IN. <http://dx.doi.org/10.5703/1288284315532>

### **Standard Specification for Lightweight Aggregate for Internal Curing of Concrete ASTM C1761 / C1761M 17**

This specification covers LWA intended to provide water for IC of concrete. It includes test methods for determining the absorption and desorption properties of LWA.

ASTM C1761/C1761M-17. 2017. *Standard Specification for Lightweight Aggregate for Internal Curing of Concrete*, ASTM International, West Conshohocken, PA. [10.1520/C1761\\_C1761M-17](https://www.astm.org/standards/C1761).

### **Internal Curing for Concrete Pavements**

A Tech Brief was developed to provide information on IC for concrete pavements by describing the primary concepts behind IC as well as describing aspects of practical applications, mixture design, construction, and quality control (QC). A document with supporting references is available as well.

Weiss, J. 2016. *Internal Curing for Concrete Pavements*. Tech Brief FHWA-HIF-16-006. Federal Highway Administration, Washington, DC. <https://www.fhwa.dot.gov/pavement/concrete/pubs/hif16006.pdf>.

Weiss, W. J. and D. Morian. 2017. A Review of Internally Cured Concrete as It Relates to Pavements. Transportation Research Board 96th Annual Meeting, January 8–12, Washington, DC. [17-03454](#).

## **C. WEBSITES RELATED TO INTERNAL CURING**

The following websites and videos are recommended for obtaining in-depth guidance on the design and construction of internally cured concrete.

- <http://cce.oregonstate.edu/internalcuring>
- <https://ciks.cbt.nist.gov/~bentz/phpct/database/ic.html>
- <http://www.escsi.org/ContentPage.aspx?id=1062>
- [http://www.escsi.org/ContentPage.aspx?id=1242&ekmense1=cb1fced2\\_61\\_74\\_1242\\_10](http://www.escsi.org/ContentPage.aspx?id=1242&ekmense1=cb1fced2_61_74_1242_10)
- <https://www.youtube.com/watch?v=aPyWD-rnvcw&feature=youtu.be>
- [https://www.youtube.com/watch?v=\\_ZnLG-MVuel&feature=youtu.be](https://www.youtube.com/watch?v=_ZnLG-MVuel&feature=youtu.be)

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# Standard Practice for Internally Cured Concrete Mixtures

## 1. SCOPE

- 1.1. This document consists of information related to furnishing and placing internally cured concrete. In general, internally cured concrete follows all specifications for conventional concrete specification, manufacture, and placement with the exception of the additional items mentioned in this document. This includes concrete for pavements, bridge decks, patches and repairs, substructure, and other elements.

Recent studies have demonstrated potential benefits of using internally cured (IC) concrete [1-5]. These benefits include the following:

- a reduction in shrinkage cracking due to autogenous, plastic, and drying shrinkage
- an increase in the degree of hydration (DOH) of cements and degree of reaction of supplementary cements
- improved service life of concrete elements due to reduced transport and reduced corrosion of reinforced elements at cracks
- a potential to reduce the built-in stress and curling in flatwork paving and patching elements
- a potential to reduce the wet curing time

It has been shown that internal curing can have benefits on the service life [6], operations costs [7], and social costs of transportation facilities [8].

- 1.2. Internally cured concrete is a class of concrete made in which either (a) prewetted lightweight fine aggregate (LWFA) is substituted for a portion of the conventional fine aggregate, or (b) SAPs are used to absorb additional mix water before setting (additional mix water is added to the mixture that results in a portion of the pore solution being absorbed by the SAP that is not considered in determination of the w/cm ratio). The prewetted LWA or SAP will be referred to as IC agents. This document refers to the manufacturer of internally cured concrete with LWA primarily because this method is currently available; however, notes will be provided regarding the use of SAP as an IC agent.

Internally cured concrete is most commonly made by replacing a portion of the fine aggregate in concrete with prewetted LWFA [9,6]. Water remains in the LWA during mixing and until the time of set; however, at the time of set capillary stresses develop in the concrete that draw the water out of the LWA and cure the concrete section [10,11]. Although a wide range of design principles has been developed, a simple spreadsheet that can be used to design these concrete mixtures [12,13] has also been developed. This approach will be described in great detail in the remainder of the document.

Internally cured concrete is most commonly made by replacing a portion of the fine aggregate in concrete with prewetted LWFA; however, it can also be made by using SAPs [14]. Currently there are—to the best of the author's knowledge—no SAP materials on the approved materials lists for DOTs. The engineer shall request the demonstrated ability of the SAP to absorb pore fluid and needs to know its absorption capacity (a provisional specification is provided in the appendix). The engineer should also request information demonstrating the use of the SAP to maintain a high relative humidity while not negatively impacting typical properties like compressive or flexural strength, volume change, transport properties, or freeze-thaw resistance of the concrete. The SAP should also be demonstrated as able to be added to the concrete, dispersed, and pumped using conventional placement methods.

- 1.3. The IC agent (LWFA or SAP) will maintain in the concrete mixture through its life. The water absorbed by the IC agent before set is used for IC and does not contribute to the

w/cm ratio of the mixture. A substantial portion of water absorbed by an IC agent (assuming the IC agent has sufficient desorption capabilities) will be released after setting with the intention of aiding in the curing of concrete.

The w/cm ratio is a term that is used to describe the pore structure that develops in a concrete. The mass of water that is used in the determination of the w/cm ratio is the free water in the concrete (i.e., water that is not absorbed by the aggregate) because this water will influence the porosity of the cementitious matrix.

- 1.4. Internally cured concrete can contain portland cement, portland limestone cement, SCM(s), fine aggregate, LWFA, coarse aggregate, coarse LWA, SAP, concrete admixtures (e.g., water reducing, air entraining, corrosion inhibiting), or fiber reinforcement. Additional concrete-making ingredients may be added to the mixture with the approval of the engineer.
- 1.5. The internally cured concrete is intended to mitigate autogenous shrinkage and to reduce the rate of drying shrinkage to decrease the potential for early-age cracking caused by restrained shrinkage. Internally cured concrete can also aid in reducing plastic shrinkage cracking. The internally cured concrete also increases the hydration of the cement and reaction of SCMs, thereby reducing porosity of the concrete, improving durability, and utilizing the cementitious materials more efficiently.
- 1.6. When internal curing is achieved using LWA, it is generally preferred to use prewetted LFWA rather than coarse LWA because of improved particle spacing at lower aggregate substitutions. This enables fluid to be drawn more rapidly from the aggregate and more uniformly provide curing water throughout the paste; however, either fine or coarse LWA can be used to provide IC.

Internal curing is achieved using either prewetted LWFA or coarse LWA. LWFA is superior to coarse LWA because of improved particle spacing at lower aggregate substitutions. It was shown that internal curing with LWFA is superior to coarse LWA in terms of freeze-thaw resistance [15].

**Note 1**—The terms prewetted and saturated surface dry (SSD) are frequently used interchangeably when discussing LWA for use in IC. In general, prewetted is a preferred term to recognize a state in which the aggregate is not substantially releasing water to the fresh concrete mixture or absorbing water from the fresh concrete mixture during mixing. However, strictly speaking, aggregates that are prewetted are not in the SSD condition because they are generally not completely saturated [16].

- 1.7. This specification is intended to provide state highway agencies (SHAs) flexibility in their approach to the use of IC. As such, this specification includes notes that incorporate a range of choices that can be selected to best fit the needs of the agency.
- 1.8. This specification is silent on many of the practices used in the manufacture, sampling, and testing of other aspects of concrete. As such, this document should be viewed as a supplement to existing concrete specifications—not a complete replacement.
- 1.9. The values stated in the International System (SI) of units are to be regarded as the standard. The values given in parentheses are provided for information only.
- 1.10. Quality control (QC) is an essential part of the production and construction process.
- 1.11. It should be noted that in general internally cured concrete should be viewed as an enhancement to producing high-quality concrete and should not be viewed as a method to replace good concrete practices related to workmanship and curing.

- 1.12. The use of internally cured concrete in some areas has been accompanied by a reduction in the time of wet curing; however, in many cases the external curing requirements are the same as with conventional concrete.

The use of internally cured concrete in some areas has been accompanied by a reduction in the time of wet curing [17]; however, in many cases the external curing requirements are the same as with conventional concrete [6]. Research is still under way to quantify the benefits of IC as it relates to reduced time of external curing [18].

- 1.13. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

## 2. REFERENCED DOCUMENTS

### 2.1. AASHTO standards

- T 22, Compressive Strength of Cylindrical Concrete Specimens
- T 23, Making and Curing Concrete Test Specimens in the Field
- TP 95, Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration
- TP 118, Characterization of the Air-Void System of Freshly Mixed Concrete by the Sequential Pressure Method
- TP 119, Electrical Resistivity of a Concrete Cylinder Tested in a Uniaxial Resistance Test
- T 121, Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
- T 334, Estimating the Cracking Tendency of Concrete
- R 39, Making and Curing Concrete Test Specimens in the Laboratory
- TP 363-17, Dual Ring Test

### 2.2. ASTM standards

- C125, Standard Terminology Relating to Concrete and Concrete Aggregates
- C1608-12, Standard Test Method for Chemical Shrinkage of Hydraulic Cement Paste
- C1698-12, Standard Test Method for Autogenous Strain of Cement Paste and Mortar
- C1761-15, Standard Specification for Lightweight Aggregate for Internal Curing of Concrete

### 2.3. Other publications

- INDOT. 2015. *Specific Gravity Factor and Absorption of Fine Aggregate*. ITM 222-15T. INDOT Office of Materials Management. [http://www.in.gov/indot/div/mt/itm/pubs/222\\_testing.pdf](http://www.in.gov/indot/div/mt/itm/pubs/222_testing.pdf).
- NYSDOT. 2008. *Moisture Content of Fine Lightweight Aggregate*. NY 703-19 E. NYSDOT Materials Bureau, Albany, NY. [https://www.dot.ny.gov/divisions/engineering/technical-services/materials-bureau-repository/tm\\_703-19E.pdf](https://www.dot.ny.gov/divisions/engineering/technical-services/materials-bureau-repository/tm_703-19E.pdf).
- Miller, A., T. J. Barrett, A. Zander, and W. J. Weiss. 2014. Using a Centrifuge to Determine Moisture Properties of Fine Aggregate for Use in IC. *Advances in Civil Engineering Materials*, Vol. 3, No. 1, pp. 142–157. DOI:10.1520/ACEM20130111.

## 3. TERMINOLOGY

- 3.1. The definitions for concrete and concrete aggregate terms used in this specification are provided in ASTM C125.

## 4. MATERIALS

- 4.1. This specification assumes that the IC agent will be LWA. However, it is possible that the use of SAP is the IC agent with approval of the engineer<sup>1</sup>.

Lightweight aggregate (for IC)—AASHTO M 195/ASTM C1761—LWA shall be expanded shale, clay, slate, and slag meeting the requirements of ASTM C330 and ASTM C1761, except that the compressive strength and splitting tensile strength are not performed. The specific gravity factor shall be determined using the method defined in ITM 222 [after 19]. Approval of the LWA source will be determined by the engineer.

**Note 2**—Intermediate aggregates are typically those that are passing the 1/2-inch sieve and are retained on the No. 4 sieve.<sup>2</sup> As such, they fall under a coarse aggregate classification in accordance with AASHTO M 80.

## 5. SAMPLING

- 5.1. Sample aggregates in accordance with AASHTO T 2 (ASTM D75).
- 5.1.1. Reduce aggregate samples in accordance with AASHTO T 248 (ASTM C702).
- 5.2. Sample freshly mixed concrete in accordance with AASHTO R60 (ASTM C172).
- 5.2.1. Make concrete specimens in the field in accordance with AASHTO T 23 (ASTM C31).
- 5.2.2. Cure concrete specimens in the field in accordance with AASHTO T 23 (ASTM C31), with the exception that all concrete samples should be sealed until the time of testing.<sup>3</sup>

## 6. PROPORTIONING

- 6.1. Proportion internally cured concrete to comply with minimum requirements identified by the state for a concrete mixture design (CMD).<sup>4</sup>

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<sup>1</sup> As no standard specification currently exists, the use of SAP as the IC agent requires approval of the engineer. The engineer shall be provided documentation that the SAP can provide concrete that is sufficient for use. Information on the SAP such as a trade name or production name shall be provided. The absorption capacity of the SAP should be provided. The absorption capacity can be determined using synthetic pore solutions or extracted pore solutions using an approach like that outlined in AASHTO (Appendix) or some similar method. The volume occupied by the SAP with absorbed pore fluid can be accounted for by removing either an equivalent volume of sand or cement paste. Data shall be provided that demonstrate the concrete has acceptable fresh properties (AASHTO T 119, AASHTO T 152), mechanical properties (ASTM C39, ASTM C78), and durability-related performance (ASTM C666, ASTM C672, ASTM C1581, or ASTM C1698). The SAP should also be demonstrated to be able to be added to the concrete, dispersed, and pumped using conventional placement methods.

<sup>2</sup> Determining the properties of the LWFA is important for IC. A spreadsheet has been developed to help determine the absorption, desorption, surface moisture, and specific gravity. This spreadsheet is available at [13].

<sup>3</sup> Internally cured concrete samples are frequently tested in a sealed condition to demonstrate the benefits of IC. These benefits can be masked if water curing is used. [20] discusses the impact of curing conditions on IC, and although this discussion revolves around strength and hydration, it extends to properties that impact durability.

<sup>4</sup> In general internally cured concrete is similar to conventional concrete in which a portion of the fine aggregate is replaced with LWFA [2]. Internally cured concrete is often used in conjunction with high-performance concepts of limiting paste volume to reduce volume change, utilizing SCMs to densify the structure and reduce the calcium hydroxide, and reducing the transport properties of the concrete. The

6.2. Submit CMD. The format should be acceptable to the engineer.<sup>5</sup>

6.3. Mixture design criteria

The CMD shall produce workable concrete mixtures that can be placed and consolidated during construction with the following properties:

6.3.1. Paste volume—The design paste volume (sum of the volumes of cement, supplementary cement, SAP, and water) shall not exceed 26.5% of the concrete design volume (or 7.15 ft<sup>3</sup> per cubic yard of concrete).

The design volume of paste is determined by computing the volume of liquid and binder phases in a cubic yard of concrete. This means that the volume of the aggregate and air is not considered in the calculation. The volume of the paste can be determined by using Equation 6.3.1:

$$V_{Paste} \% = \frac{\sum_i^n \frac{Mass_i}{SG_i 62.4}}{27 ft^3} \times 100 \quad \text{Equation 6.3.1}$$

where:

*Mass<sub>i</sub>* is the mass of constituent *i* (e.g., cement, SCM, water, admixtures)  
*SG<sub>i</sub>* is the specific gravity of constituent *i* (e.g., cement, SCM, water, admixtures).<sup>6</sup>

6.3.2. Calculation of the w/cm ratio—The maximum w/cm ratio is 0.42. Do not include the absorbed water in the LWA or SAP as a part of the w/cm ratio calculation.<sup>7</sup>

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following section describes the proportioning concepts the SHA should be aware of, as well as the reporting requirements.

<sup>5</sup> The mixture proportions shall be provided. Two primary concepts are used to specify IC. This is described in section 6.3.4. The first concept (Option A) is to use a defined amount of LWFA in which the absorption capacity of the LWFA is well known. The NYSDOT special provision in the appendix is an example of this approach. The second concept (Option B) is to determine the volume of LWFA using an equation to provide a volume of IC water that is equivalent to the volume of chemical shrinkage. The INDOT special provision in the appendix is an example of this approach. This option can utilize mixture proportioning following the principles provided in the Excel spreadsheet [13]. These options are further described below.

<sup>6</sup> The paste volume limitation is generally used to minimize the potential for cracking due to restrained shrinkage [6,7,9]. Section 6.3.1 is a practice that is discussed in AASHTO PP 84 that has been adopted by several SHAs for use in bridge deck elements and this can be extended to account for local conditions and different elements. Local experience or applications may enable the engineer to alter the paste volume limit. In general, SCMs are frequently utilized and the following are some rules of thumb that can be considered.

- Cement content in the mixture shall be at least 390 lbs/yd<sup>3</sup> of concrete.
- SCM—The mass of the SCM should be limited to half the mass of the cementitious material. This is done to avoid depassivation of the reinforcing steel.
- Silica Fume Limit—If silica fume is used, it should constitute less than 8.0% of the total cementitious content of the system by mass. This limit is generally used to reduce workability issues in the field.
- Metakaolin Limit—If metakaolin is used, it should typically constitute less than 8.0% of the total cementitious content of the system by mass. This limit is generally used to reduce workability issues in the field; however, this depends on the grind of the metakaolin. The coarser the grind the higher percent and can go up to !5%.



6.3.3. The w/cm ratio of the delivered material should be within a range of +/- 0.025 of the target in the approved CMD and shall not exceed 0.42. The contractor shall achieve this by controlling water added to the batch and water occurring as surface moisture on the aggregates.<sup>8</sup>

6.3.4. LWA volume. (Choose one option—6.3.4.1 or 6.3.4.2—and delete the other option from the specification or make a conscious decision to enable the concrete contractor to select one option.)

6.3.4.1. Option A—The weight (mass) of the oven-dry LWA shall be 285 lb/yd<sup>3</sup> of concrete and the LWA shall have a 24-hour absorption of at least 15%. If this option is selected, it is assumed that the design 24-hour absorption of the aggregate is 15%.

6.3.4.2. Option B—The weight (mass) of the LWA used for IC should be determined using the following equation:

$$M_{D-LWA} = \frac{C_F C_{S-ULT} \alpha}{\phi_{24Hr} S} \quad \text{Equation 6.3.4.2}$$

where:

$C_f$  is the cementitious content including the weight of cement and any SAM

$C_{S-ULT}\alpha$  is the ultimate chemical shrinkage at the maximum degree of hydration of the cement and degree of reactivity of the SCM (document to add as reference)

$\phi_{24Hr}$  is the 24-hour absorption as determined by [19].

$S$  is the degree of saturation when compared with the 24-hour value. This value may be greater than 1.

6.3.5. There will be no calendar date restrictions as to the use of internally cured concrete (Note 3)

**Note 3**—It is vital that the w/cm ratio and minimum cold weather temperature conditions are maintained to avoid freeze-thaw damage in fresh concrete.<sup>9</sup>

6.4. Concrete strength/Flexural strength<sup>10</sup>

6.5. Cracking tendency of concrete

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<sup>7</sup> Internally cured concrete can be used with a wide range of concrete mixtures; however, it is frequently observed to work best with mid- to low-range w/cm ratios (0.42 and lower). If the water content of the concrete becomes too low, it may be difficult to entrain air in the mixture.

<sup>8</sup> To accurately control the water content and w/cm ratio of the mixture, it is recommended that the contractor follow ITM 222 and use the centrifuge to carefully monitor the moisture properties of the LWFA. This can be done using the spreadsheet from [13]. Because of the low volume of water added to these mixtures, it is also important that other aspects of good-quality concrete construction are followed such as limiting wash-down water remaining in the truck.

<sup>9</sup> It was shown that capillarity will draw water from LWA to reduce the potential for freeze-thaw damage in internally cured concrete at early ages. As such, it is important that internally cured mixtures not have excessive IC water or an excessively high w/cm ratio to improve their freeze thaw durability [15].

<sup>10</sup> Compressive strength or flexural strength should be specified as done with conventional concrete. It is generally observed that the compressive (flexural) strength is within +/- 10% of the compressive strength (or flexural strength) of the conventional concrete. Whereas the addition of the LWFA may reduce strength due to the addition of the porous aggregate particles, the increased degree of hydration provided by IC often increases the strength of the concrete [2,21].

- 6.5.1. The volume of the paste should be less than or equal to 26.5%.

**Note 4**—If a performance requirement is required, AASHTO 334 (The Dual Ring) can be used. In this test, the internally cured concrete should be placed in the dual ring and tested for seven days following the curing procedure used in the field. The stress that develops in the ring shall be less than 60% of the splitting tensile strength when tested in the dual ring with a temperature of  $23 \pm 1^\circ\text{C}$  ( $73.4 \pm 1.8^\circ\text{F}$ ), and relative humidity (RH) of  $50 \pm 2\%$ , RH for seven days.<sup>11</sup>

- 6.6. Durability of hydrated cement paste in freeze-thaw environments

- 6.6.1. A target air content shall be set to be 6.5%. The air content shall be between 5 and 8% using AASHTO T 152 or AASHTO T 196. (See Note 5 if AASHTO TP 118 is to be used.)

**Note 5**—It is possible to permit air contents measured by AASHTO TP 118 if desired.<sup>12</sup>

- 6.6.2. If salt damage due to  $\text{CaCl}_2$  or  $\text{MgCl}_2$  is a concern, the SCM should be used to replace the cement with a volume of at least 30% or a topical treatment (sealer) should be used consistent with AASHTO M 224. (See Note 6.)

**Note 6**—The use of SCMs reduces the volume of calcium hydroxide (CH) in the mixture, and as such the potential for salt damage is reduced.<sup>13</sup>

- 6.7. Transport properties (choose at most one of the following options)<sup>14</sup>

- 6.7.1. Formation factor—A formation factor at an equivalent age of 91 days of greater than 1500<sup>15</sup>.

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<sup>11</sup> It has been shown that when the concept of IC is followed, the autogenous shrinkage is very low, as is the potential for autogenous cracking; as such it is likely not essential to run the ring test [9,10]. It has also been shown that there can be some benefit in reducing the rate of drying shrinkage and potential for cracking; however, IC does not eliminate the potential for drying shrinkage cracking [11].

<sup>12</sup> One question that frequently comes up is the ability to pump internally cured concrete or to use the pressure test method. As the aggregates are partially saturated, they appear to not substantially alter the measured air volume, assuming the aggregate corrections are provided [15]. Additionally, a question that arises with internally cured concrete is the ability to pump the concrete without substantial fluctuations in air content. Both testing by the NYSDOT [4] and INDOT [6] have not reported any greater chance for fluctuations in air content than that observed in typical concrete construction.

<sup>13</sup> Internally cured concrete has been shown to have similar durability to conventional concrete with respect to freeze-thaw performance as long as a sufficient air content has been achieved [15]. Internally cured concrete can also be shown to be resistant to salt damage, provided the CH content of the concrete is reduced by utilizing SCMs.

<sup>14</sup> Internally cured concrete has been shown to have similar or improved transport properties when compared to conventional concrete. The improved transport performance generally is attributed to increased hydration and the densification of the interfacial transition zone [14].

<sup>15</sup> The Arrhenius equation can be used to enable curing samples at a high temperature to test them at an early age but with an equivalent long-term age. Specifically, by curing for 3 days at  $23^\circ\text{C}$  ( $73^\circ\text{F}$ ) followed by 25 days of curing at  $50^\circ\text{C}$  ( $122^\circ\text{F}$ ) results in an equivalent curing of 91 days. By curing for 3 days at  $23^\circ\text{C}$  ( $73^\circ\text{F}$ ) followed by 110 days of curing at  $50^\circ\text{C}$  results in an equivalent curing of 365 days. It should be noted that the temperature should not be raised about  $50^\circ\text{C}$  ( $122^\circ\text{F}$ ) avoid potential reactions that will not occur naturally. Other agencies would prefer to use different temperature regimes such as 3 days at  $23^\circ\text{C}$  ( $73^\circ\text{F}$ ) followed by 27 days at  $37.8^\circ\text{C}$  ( $100^\circ\text{F}$ ) which can be computed to have an equivalent age of 56 days [22].

**Note 7**—The acceptance for each project could be written in terms of resistivity once the pore solution is obtained for the mixture.

**Note 8**—The formation factor can be defined at a different age or at a different required value depending on required anticipated performance for a given concrete exposure, with a given level of cover at a given age. Guidance on this approach is provided in [21], for example.

#### 6.7.2. Determining the formation factor ( $F$ )

The formation factor ( $F$ ) is a parameter that describes the pore geometry and connectivity of saturated concrete. The formation factor is computed using equation 6.7.2.a:

$$F = \frac{\rho \text{ } [\Omega \cdot m]}{\rho_o \text{ } [\Omega \cdot m]} \quad \text{Equation 6.7.2.a}$$

where

$\rho$  is the resistivity of a bulk concrete as determined using AASHTO TP 95 or TP 119

$\rho_o$  is the resistivity of the pore solution from 6.2.12 as a part of the CMD

**Note 9**—Recent work has indicated that measurement of the formation factor on sealed resistivity samples can be performed. This requires a correction like that shown in equation 6.7.2b:

$$\rho_{\text{sealed}} \text{ } [\Omega \cdot m] = \rho_{\text{saturated}} \text{ } [\Omega \cdot m] S^{-m} \quad \text{Equation 6.7.2.b}$$

where

$\rho_{\text{sealed}}$  is the resistivity of a sealed sample,  $\rho_{\text{saturated}}$  is the resistivity of a saturated sample, and  $m$  is the saturation coefficient.<sup>16</sup>

6.7.3. Rapid chloride permeability test (RCPT)—A maximum charge passed at an equivalent age of 91 days can be specified (ASTM 1202).

#### 6.8. Durability (aggregate stability)

6.8.1. Evaluate aggregates for the potential susceptibility to damage due to freezing and thawing (D-cracking) using ASTM C1646 and AASHTO T 161, or accepted local SHA practice.

6.8.2. Evaluate aggregates for the potential susceptibility to alkali-aggregate reactivity using AASHTO PP 65.

6.8.2.1. Comply with mitigation strategies described in AASHTO PP 65 if aggregates susceptible to alkali-silica reaction (ASR) are used.

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<sup>16</sup>(If needed in section 6.8, the agency shall make a determination of which option they prefer the contractor use.) The pore solution resistivity at 56 days as determined by either (a) assumption of 0.1Ωm, (b) calculation using the mixture proportions for saturated curing (using the website <https://ciks.cbt.nist.gov/poresolncalc.html> or with an equivalent method), or (c) pore solution extraction as determined using an accepted methodology (testing method to be developed). This value shall be determined at the time of the mixture submittal/trial batch and maintained as constant throughout the project unless a change in materials or mixture design occurs. The saturation coefficient is generally a unitless number that generally ranges from 3 to 5 [15].

**Note 10**—Accepted SHA practice should be used to address local durability issues not addressed in this specification.

## 7. CONCRETE ACCEPTANCE REQUIREMENTS

7.1. Fresh concrete shall be accepted based on the following:

7.1.1. Air content of greater than 5% after placement using AASHTO T 152, T 196. (See Note 11 if AASHTO TP 118 is to be used.)

**Note 11**—It is possible to permit a reduction in the air content assuming the measured super air meter (SAM) number is less than 0.20 using AASHTO TP 118.

7.2. Hardened concrete shall be accepted based on the following:

7.2.1. The minimum concrete compressive strength or flexural strength.

7.2.2. The minimum saturated formation factor or RCPT at 56 days.

**Note 12**—The acceptance for each project could be written in terms of resistivity once the pore solution is obtained for the mixture.<sup>17</sup>

## 8. QUALITY CONTROL

8.1. A trial batch shall be conducted by the contractor unless stated in writing by the engineer that this is not required based on previously demonstrated capability to manufacture internally cured concrete.<sup>18</sup>

8.1.1. The purpose of the trial batch is to demonstrate that the mixture design and batching methods meet the requirements of the specification.

8.1.2. A representative of the LWA supplier or SAP supplier shall be present to aid with technical expertise associated with the use of the LWA or SAP.

8.1.3. The engineer, or their representative, shall be present for the trial batch.

8.1.4. The contractor shall construct LWA piles similar to those planned for construction. The LWA shall be prewetted in accordance with section 8.4.

8.1.5. Prior to concrete production in the trial batch, the LWFA will be tested for fineness modulus in accordance with ASTM C330 and 24-hour absorption capacity, desorption, and relative specific gravity in accordance with ITM 222. These values will be established for the mixture design.

8.2. Develop and submit a QC plan for approval prior to beginning work.

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<sup>17</sup> In general, the standard acceptance procedures are still utilized for internally cured concrete as with conventional concrete. Additional information shall be provided to insure that the aggregates meet the required absorption, desorption, and moisture. Further additional testing is under way to utilize a rapid RH measurement for internally cured concrete as an acceptance test [17].

<sup>18</sup> The trial batch is used to make sure that the contractor and batching plant understand the changes associated with the use of the LWFA. Specific aspects that should be considered during the trial batch include confirming the programming of batching software, satisfactory measurement of aggregate moisture, aggregate moisture conditioning and stockpiling, and fresh and hardened properties that meet the specification [6]. Specific factors that should be considered in the programming of the software include the ability to add the aggregate porosity, as this is often limited in software and needs a “work around.” Further, the need to make sure the “gate jog” is properly calibrated for LWA is essential.

- 8.2.1. The QC plan shall include, but not be limited to, the following:
  - 8.2.1.1. Detailed descriptions of actions to monitor the quality of constituent materials, construction processes, and the final product including test methods and frequencies of those tests.
  - 8.2.1.2. Examples of how QC data will be managed and reported, including the use of control charts exhibiting acceptable ranges and control limits.
  - 8.2.1.3. Detailed descriptions of actions to be taken when control limits are exceeded.

**Note 13**—Target values and action limits should be set.

- 8.2.2. It is expected that at a minimum the acceptance criteria in section 7 will be evaluated along with LWA surface moisture and absorption.<sup>19</sup>
- 8.3. Prior to concrete production, the LWFA will be tested for fineness modulus in accordance with ASTM C330 and 24-hour absorption capacity, desorption, and relative specific gravity in accordance with ITM 222. These values will be established for the mixture design.
- 8.4. Prewetting of the LWFA
  - 8.4.1. When prewetted LWA is used in the mixture, stockpile(s) shall be prepared at the production facility designed to maintain uniform moisture throughout the pile. A sprinkler (or wetting) system shall be approved by the project engineer. Manipulation of the pile during wetting may be necessary to assure uniform wetting and drainage.
  - 8.4.2. Continuously and uniformly sprinkle the stockpile(s) with water for a minimum of 48 hours. If a steady rain of comparable intensity occurs, turn off the sprinkler system at the direction of the project engineer until the rain ceases. At the end of the wetting period, or after the rain ceases, allow stockpiles to drain for 12 to 15 hours immediately prior to use, unless otherwise directed by the project engineer. The prewetted and drained LWA shall achieve and maintain an “absorbed moisture content” of the aggregate in the stockpile equal to or greater than the 24-hour absorbed moisture content as determined by ITM 222 (Note 14). Transfer of aggregate during the mixing process shall be monitored and controlled by the contractor to assure consistent surface moisture such that the aggregate does not significantly increase the w/cm ratio of the batched concrete.  
**Note 14**—Some may elect to determine the 24-hour absorbed moisture content using NY 703-19 E as an alternative to ITM 222. The methods are compared in [19].
- 8.5. Moisture corrections during batching
  - 8.5.1. The moisture content and specific gravity factor of the LWFA shall be determined immediately prior to batching, using ITM 222 (note 8.2.2a).<sup>20</sup>

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<sup>19</sup> It is suggested that the producer include some language to describe how variations in absorbed moisture content will be accounted for during mixing. In general, absorptions greater than the design 24-hour absorbed moisture content are of little consequence; however, values lower than the design 24-hour absorbed moisture content would require the mixture to be redesigned. Variations in the surface moisture require adjustments to the batching water, and this should be documented in the QC plan.

- 8.5.2. The LWFA, at the time of batching, must have a 24-hour absorbed moisture that is equal to or greater than the design 24-hour absorbed moisture content.<sup>21</sup>
- 8.5.3. The adjusted weight must be supplied to account for the actual absorbed moisture content, so that the mix design entered into the automated batching system is based on SSD weight. After the adjusted mix design is entered into the batching system, additional adjustments must be made to the fine aggregate and water quantities to account for the “surface” moisture of the fine aggregates.
- 8.6. Batch the LWFA first, then batch the fine aggregate, coarse aggregate, admixtures, cement, supplementary cements, and remaining mixing water.<sup>22</sup>
- 8.7. The LWFA shall be removed from the pile and turned prior to and during batching to promote uniform moisture.<sup>23</sup>
- 8.8. The lightweight aggregate manufacturer service representative shall be available at the site for the first two days of concrete placement operations to assist in the control of internally cured concrete mixing and placement operations.<sup>24</sup>
- 8.9. External curing practices that follow the current specification should be maintained.<sup>25</sup>
- 8.10. Cold-weather operations shall be in accordance with conventional concrete requirements of the SHA, except that immediately after the pour is complete the freshly placed concrete and forms shall be covered to form a protective enclosure and the air in the enclosure kept at a temperature above 50°F (10°C) until a concrete maturity is achieved

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<sup>20</sup> The frequency of this testing depends on the size of the job and the speed at which the material is being used. For many smaller projects, the volume of aggregate will be one small pile that can be relatively uniformly wetted and the moisture can be maintained on the day of casting. Moisture shall be taken for the initial batching and every 100 yd<sup>3</sup> of concrete produced. For larger projects such as paving, this may be relaxed after the production of 500 yd<sup>3</sup> of concrete per approval by the engineer. It should be noted that care should be taken if producers store the LWA in the plant overnight because frequently changes in moisture content are observed with the aggregate draining, resulting in an aggregate that has less moisture than tested.

<sup>21</sup> This is done to make sure that the mixture is being conservatively used. It has been observed that some producers aggressively increase the expected design 24-hour absorbed moisture content, which is not encouraged since if this value is not obtained the concrete is not obtaining sufficient IC and the mixture should be redesigned to increase the LWFA volume. On the contrary, however, if the design 24-hour absorbed moisture content is exceeded, the design mixture proportions can be used conservatively.

<sup>22</sup> Many SHAs require that the LWFA is batched initially so that it is done more accurately. Many SHAs also require adjustments to the “jog rate” on the plant to make sure that the LWFA is accurately dosed into the mixture.

<sup>23</sup> The intention of this requirement is to help maintain uniform absorbed moisture and surface moisture for the LWA during the batching process. When this is done, care should be taken to not include approximately 6 inches of material from the bottom of the pile where the aggregates are wetted because this is known to be dramatically different from the remainder of the pile after drain-down.

<sup>24</sup> Many SHAs have used this in specifications as they begin to become familiar with internally cured concrete. As the SHA and producers become more familiar with the internally cured concrete, this is often relaxed and the requirement is either to have an LWA manufacturer present or to demonstrate experience with internally cured concrete.

<sup>25</sup> The curing shall be provided through curing compound or wet burlap curing as specified in the current specifications. In general, water curing is better for concrete because additional water can be absorbed; however, internally cured concrete works well with curing compounds [21]. The use of internally cured concrete in some areas has been accompanied with a reduction in the time of wet curing [17]; however, in many cases the external curing requirements are the same as with conventional concrete [8]. Research is still under way to quantify the benefits of IC as it relates to reduced time of external curing [18].

that is at least equivalent to that obtained by curing the concrete for seven days at 70°F (23°C) (note 8.9.2.a).

**Note 15**—The engineer may replace the equivalent concrete maturity recommendation with curing at 50°F (10°C) for at least 240 hours.<sup>26</sup>

8.11. Submit testing results and summary of any corrective actions taken on a daily basis.<sup>27</sup>

## 9. TEST REPORTS

9.1. Submissions shall be those typically used by the SHA, including the following:

- Submit test reports for all materials to be used in the concrete mixture as noted in accordance with Section 6.
- Submit revised CMDs when a change in the source or brand of any materials or product is proposed as directed by the SHA.
- Submit laboratory test data and samples of all materials to be used in the mixture, identifying the proposed source or manufacturer of the materials.<sup>28</sup>
- Submit test reports for concrete properties as noted in accordance with Section 6.<sup>29</sup>
- Submit test reports for QC and acceptance in accordance with Sections 7 and 8.<sup>30</sup>

## 10. REFERENCES

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<sup>26</sup> Commentary—Internally cured concrete contains additional water (the curing water) when it is in the fresh state. As with conventional concrete, internally cured concrete is sensitive to setting prematurely because of the high water content of the mixture. As such, care should be taken to avoid the freezing of concrete at early ages.

Internally cured concrete relies on the relatively low w/cm ratio to create capillary suction, which draws water out of the LWA at early ages, thereby improving its freeze-thaw resistance. [15] demonstrated that properly designed internally cured mixtures are freeze-thaw durable. It was, however, shown that mixtures where the w/cm ratio was too high (e.g., > 0.5) or where excessive IC water was added (e.g., greater than twice that obtained from Equation 6.3.10.2) may be susceptible to freeze-thaw damage.

<sup>27</sup> Whereas this is typical in an SHA specification, it is important to make sure that any unique items associated with the internally cured concrete are noted as the SHA gains experience with this material.

<sup>28</sup> For internally cured concrete, this shall include information on LWA or SAP used in the mixture.

<sup>29</sup> For internally cured concrete, this shall include information on the absorption of LWA or SAP.

<sup>30</sup> For internally cured concrete, this shall include information on mixture proportion adjustments for IC. This should include approaches to prewetting LWA prior to batching, any modifications to external curing requirements for test specimens (such as sealed curing), and any modifications to external curing requirements for the constructed section (such as time of moist curing).

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# APPENDIX

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## Recommended Standard Method of Test for

# The Absorption of Superabsorbent Polymers for Use in Portland Cement-Based Concrete Systems

Internally cured (IC) concrete is most commonly made by replacing a portion of the fine aggregate in concrete with prewetted lightweight fine aggregate (LWFA); however it can also be made by using superabsorbent polymers (SAPs) [1]. Currently, there are, to the best of the authors' knowledge, no SAP materials on the approved materials lists for DOTs. The engineer shall request the demonstrated ability of the SAP to absorb pore fluid and to know the absorption capacity (the provisional test method is provided in this appendix). The engineer should also request information demonstrating the use of the SAP to maintain a high relative humidity in the concrete while not negatively impacting typical properties like compressive or flexural strength, volume change, transport properties, or freeze-thaw resistance of the concrete. The SAP should also be demonstrated to be able to be added to the concrete, dispersed, and pumped using conventional placement methods.

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### 1. SCOPE

- 1.1. This test method covers the procedure for quantitative determination of the fluid absorption of SAPs for use in portland cement-based concrete systems.
- 1.2. The values stated in SI units are to be regarded as the standard.
- 1.3. *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

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### 2. REFERENCED DOCUMENTS

- 2.1. *AASHTO standards:*  
M 231, Weighing Devices Used in the Testing of Materials
- 2.2. *ASTM standards:*  
D1193, Reagent Water
- 2.3. *Other standards:*  
Reagent Chemicals, Specifications, and Procedures for Reagents and Standard-Grade Reference Materials, Committee on Analytical Reagents of the American Chemical Society

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### 3. SUMMARY OF TEST METHOD

- 3.1. This test method covers the procedure for quantitative determination of the absorption of SAPs for use in portland cement-based concrete systems.

- 3.2. The absorption of the SAP is highly dependent on the ionic strength of the solution being used [1]–[3]. The type of solution to be used for the experiment needs to be chosen depending on the final application of the SAPs. This test method is focused on the determination of the absorption of SAPs for use in portland cement-based concrete systems that contain cement, supplementary cement, and a wide range of chemical admixtures.
- 3.3. A known quantity of SAP is introduced in a dry teabag of known mass and absorption. The teabag is then submerged in the prepared solution of known composition. The teabag is removed from the solution after 1 minute to make sure the polymers are well dispersed by very gently applying pressure with a finger, making sure to not damage the teabag. The teabag is then reintroduced into the solution, and after 30 minutes from the start of the test it is again removed and its mass is recorded. The measurements are then used to calculate the absorption of the SAP.

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#### **4. SIGNIFICANCE AND USE**

- 4.1. This test method is used for determining the amount of solution that SAPs can absorb when they are introduced to a fluid that has a similar chemical composition to that of a fresh cementitious system.
- 4.2. Calculating the amount of solution that can be initially absorbed by the SAPs is important in order to include this additional volume in the mixture design.

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#### **5. APPARATUS**

- 5.1. *Glass Beaker*—A 250-ml glass beaker in which the solution to be used can be poured.
- 5.2. *Teabag*—A commercial teabag with size approximately 50 mm long and 50 mm wide. (Note—Further work is under way to determine if this can be more accurately specified using NWSP 240.)
- 5.3. *Balance*—Analytical balance, Class A, conforming to the requirements of AASHTO M 231 to weigh the powder and the solution. The balance must have a precision of 0.1 mg.
- 5.4. *Paper Towels*—Common-use paper brown paper towels. (Note—Further work is under way to determine if this can be more accurately specified using NWSP 240).

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#### **6. SAMPLE PREPARATION**

- 6.1. *Reagents*—Reagent-grade chemicals shall be used in all tests to prepare solutions. Unless otherwise indicated, all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society.
- 6.2. *Water*—Unless otherwise indicated, water used shall be Type II reagent water in accordance with ASTM D1193.
- 6.3. *Solution*—The solution needs to be prepared in conformity with the aim of the experiment. The solution can be either a simulated pore solution or an actual early-age extracted pore solution. By following the procedure described in this standard, 30 g of solution should be adequate for the completion of the experiment. The 30 g is a conservative value, which covers the whole range of absorptions. Measurements on highly concentrated ionic solutions, where the absorption of SAP tends to be lower, might be performed with 10–15 g of solution.

**Note 1**—The pore solution composition depends on the cementitious materials and chemical admixtures, the chemical composition of the cementitious materials and chemical admixtures, and proportions of the materials used in concrete, but typically it contains sodium, potassium, calcium, sulfate, and hydroxide ions.

- 6.4. *Superabsorbent Polymers*—The SAPs used for this experiment must be at an initial dry state. The sample shall be stored at 50°C for 24 hours prior to the test with a mass loss of less than 0.1% over 1 hour.
- 6.5. *Teabag Absorption*—Fill a clean glass beaker with approximately 30 g of the same solution for which the measurement of the SAP absorption is intended.

Measure the mass of the dry teabag.

Immerse the teabag in the solution.

After 30 minutes from the time of immersion, extract the soaked teabag and tap it on paper towels for a total of eight times, alternating the side of the teabag for each tap. Use a dry area of the paper towel during each tap. At each tap, put gentle pressure on the top surface the teabag to ensure contact with the paper towel and allow the transfer of the surface moisture. This process ensures surface dry conditions for the teabag.

Record the mass of the teabag as soaked surface dry mass.

The absorption of the teabag is then measured as:

$$\Phi_{TB,30} = \frac{M_{SD,TB} - M_{D,TB}}{M_{D,TB}} \quad (1)$$

where:

$\Phi_{TB,30}$  = absorption of teabag at 30 minutes, g/g

$M_{SD,TB}$  = mass of teabag in soaked surface dry condition, g

$M_{D,TB}$  = mass of dry teabag, g

**Note 2**—The same solution used to measure the absorption of the teabag might be used for the absorption measurement of the SAP. Nevertheless, it should not be reused for multiple SAP absorption measurements.

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## 7. TESTING PROCEDURE

- 7.1. Weigh  $50 \pm 0.5$  mg of dry SAP.
- 7.2. Introduce the SAP inside the teabag and weigh the mass of the teabag with SAP. Make sure the SAP is sufficiently dispersed at the bottom of the teabag.
- 7.3. Measure 30 g of solution in a beaker.
- 7.4. Fold the teabag with SAP one to two times, in order to reduce its volume, and introduce it inside the solution, making sure that the teabag is submerged under the solution. Record the time of immersion. Cover the beaker with a material similar to Saran Wrap to minimize the potential that the pore solutions or simulated pore solutions evaporate or carbonate.
- 7.4.1. After 10 minutes of immersion time, extract the soaked teabag.

- 7.4.2. Unfold the teabag and tap it on dry paper towels eight times, alternating the side of the teabag being tapped each time. Use a dry area of the paper towel during each tap. At each tap, put gentle pressure on the top surface the teabag to ensure contact with the paper towel and allow the transfer of the surface moisture. This process ensures surface dry conditions for the teabag and SAP.
- 7.4.3. Record the soaked surface dry mass of the teabag with SAP.
- 7.4.4. Ensure that the SAP is well dispersed in the teabag and does not form any dry agglomerates. Agglomerates are easily detectable because of their white coloration. If any agglomerate is located, disperse it with a finger by gently applying pressure on it.
- 7.4.5. Resoak the teabag with SAP inside the solution after folding it one to two times.
- 7.4.6. After 30 minutes from the immersion time, remove the soaking teabag from solution and repeat tasks 7.4.2. and 7.4.3.

**Note 3**—Although this standard is written for a test time of 30 minutes, the absorption of the SAP depends on its molecular structure and the nature of the solution, and this time may vary widely[1], [2]. Therefore, if required, the test can be continued for a longer time, until the absorption plateaus.

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## 8. EXAMPLE: CALCULATION AND INTERPRETATION OF RESULTS

- 8.1. Once the mass at 30 minutes from time of immersion is collected, absorption of the SAP can be calculated as follows:

$$\Phi_{SAP,30} = \frac{M_{SD,TB+SAP} - M_{D,TB}(1 + \Phi_{TB,30}) - M_{D,SAP}}{M_{D,SAP}} \quad (2)$$

where:

- $\Phi_{SAP,30}$  = absorption of SAP at 30 minutes, g/g  
 $M_{SD,TB+SAP}$  = mass of soaked surface dry teabag and SAP, g  
 $M_{D,TB}$  = mass of dry teabag, g  
 $M_{D,SAP}$  = mass of dry SAP, g  
 $\Phi_{TB,30}$  = absorption of teabag at 30 minutes, g/g

- 8.2. Example Measurement and Calculation—The absorption of the teabag must be calculated at the beginning of the experiment. The dry mass of the bag is first measured (the following numbers are reported from an actual experiment performed using an extracted pore solution from a blended cementitious system):

$$M_{D,TB} = \text{mass of dry teabag, g} = 0.5112 \text{ g}$$

The teabag is then soaked in the prepared solution for a period of 30 minutes and then removed. Figure 1 shows the process of removing surface moisture from the teabag by tapping it eight times on dry paper towels.



**Figure 1—Tapping of the wet teabag during the absorption calculation process**

After reducing the soaked teabag to surface dry condition, the mass is recorded:

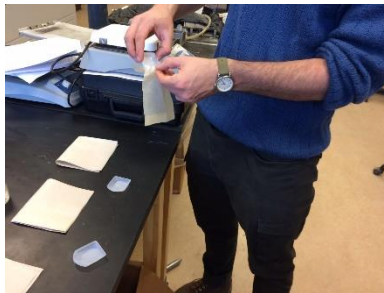
$M_{SD,TB}$  = mass of teabag in soaked surface dry condition, g = 1.5055 g

To calculate the teabag absorption, the equation described in section 6.5 is used:

$$\Phi_{TB,30} = \frac{1.5055 - 0.5112}{0.5112} = 1.945 \text{ (g/g)}$$

Once the absorption of the teabag has been calculated, select a different dry teabag, record its mass, and introduce the weighed dry SAP inside it, as shown in Figure 2. The absorption of the new teabag is assumed to be equivalent to the previous one.

$M_{D,TB}$  = mass of dry teabag, g = 0.3000 g



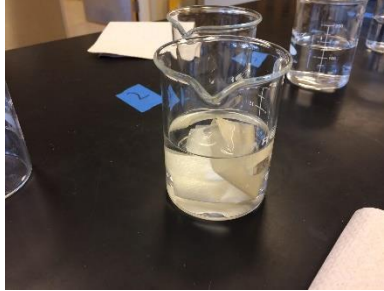
**Figure 2—Introduction of dry SAP inside the dry teabag**

At this point, remeasure the weight of the teabag + SAP and calculate the mass of dry SAP.

$M_{D,TB+SAP}$  = mass of dry teabag and dry SAP, g = 0.3490 g

$M_{D,SAP}$  = mass of dry SAP, g = 0.0490 g

Submerge them in the prepared solution, after folding the teabag one to two times, as shown in Figure 3.



**Figure 3—Soaking of the teabag + SAP inside the prepared solution**

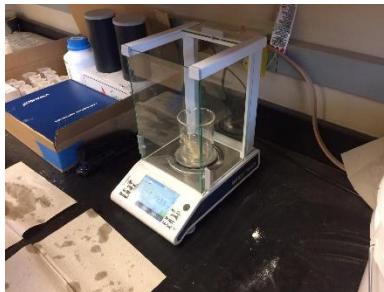
After 10 minutes from initial soaking time, extract the teabag and obtain surface dry condition by tapping it eight times on dry paper towels. Record the mass, and disperse the dry conglomerates of SAP by applying a gentle pressure wherever those are visually found.

$$M_{SD, TB+SAP, 10 \text{ min}} = \text{mass of soaked surface dry teabag and SAP at 10 minutes, g} \\ = 2.3415 \text{ g}$$

Immerse again the teabag inside the solution and wait for the 30 minutes measurement. Reduce the teabag and the SAP to surface dry conditions by tapping it eight times on dry paper towels and record their mass.

$$M_{SD, TB+SAP, 30 \text{ min}} = \text{mass of soaked surface dry teabag and SAP at 30 minutes, g} \\ = 2.3243 \text{ g}$$

Figure 4 shows the measurement procedure of the surface dry teabag + SAP mass.



**Figure 4—Measurement of mass at surface dry condition**

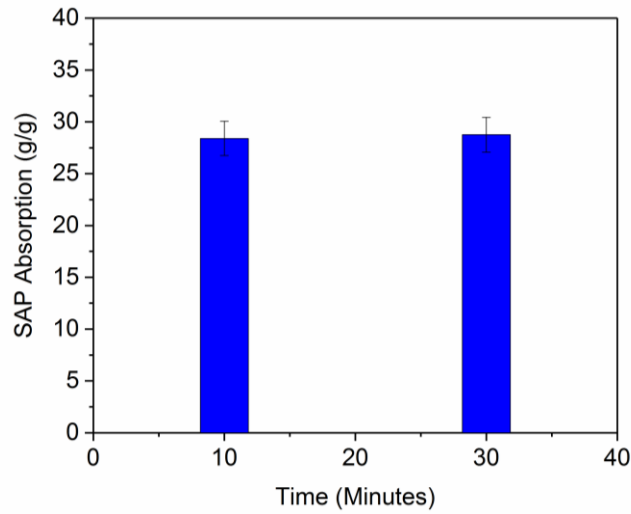
Calculate the SAP absorption at 10 and 30 minutes using the equation described in section 8.1.

$$\Phi_{SAP, 10 \text{ min}} = \frac{2.3243 - 0.3000(1 + 1.945) - 0.0495}{0.0495} = 28.11 \text{ (g/g)}$$

$$\Phi_{SAP, 30 \text{ min}} = \frac{2.3415 - 0.3000(1 + 1.945) - 0.0495}{0.0495} = 28.45 \text{ (g/g)}$$

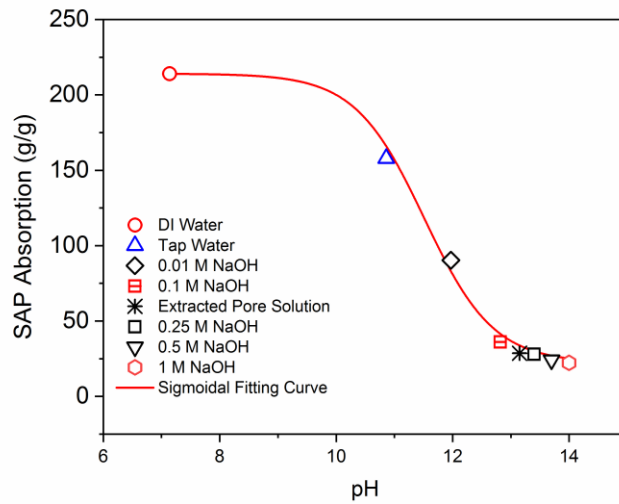
Figure 5 shows the absorption values calculated following this procedure at 10 and 30 minutes.





**Figure 5—Absorption calculation example**

Figure 6 shows the influence of pH on the absorption of a tested SAP.



**Figure 6—SAP absorption as a function of the solution pH [3]**

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## 9. REPORT

9.1. *Report the following, if known:*

9.1.1. Solution properties—Solution composition and pH

9.1.2. SAP name

9.1.3. SAP absorption (and soaking time if it differs from 30 minutes) calculated following this procedure

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## 10. PRECISION AND BIAS

10.1. *Precision:*

10.1.1. *Single-Operator Precision*—The single operator coefficient of variation of a single test result has been found to be 5.83%. Therefore, the results of two properly conducted tests by the same operator on the SAP are not expected to differ by more than 5.83% of their average.

10.1.2. *Multilaboratory Precision*—No data is currently available on experimental variation between multiple laboratories.

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## 11. KEYWORDS

11.1. SAP, absorption, solution

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## 12. REFERENCES

- [1] Zhao, Y., H. Su, L. Fang, and T. Tan. 2005. Superabsorbent Hydrogels from Poly(Aspartic Acid) with Salt-, Temperature- and pH-Responsiveness Properties. *Polymer*, Vol. 46, No. 14, pp. 5368–5376.
- [2] Zohuriaan-Mehr, M. J. and K. Kabiri. 2008. Superabsorbent Polymer Materials: A Review. *Iranian Polymer Journal*, Vol. 17, No. 6, pp. 451–477.
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- [4] Mechtcherine, V. and H. W. Reinhardt, Eds. 2012. *Application of Superabsorbent Polymers (SAP) in Concrete Construction - State-of-the-Art Report Prepared by Technical Committee 225-SAP*. Springer. Unedited version available at [https://www.rilem.net/global/gene/link.php?doc\\_id=3497&fg=1](https://www.rilem.net/global/gene/link.php?doc_id=3497&fg=1).
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