Another Look at the Drying of Lightweight Concrete

A comparison of drying times for normalweight and lightweight floors

by Peter Craig and Bill Wolfe

Lightweight concrete has been successfully used in buildings for over 80 years.[1] However, as reports of moisture-related flooring problems have escalated in the past decade, the drying time of lightweight concrete has attracted much attention.

A key issue is the volume of water in lightweight concrete. It's a standard practice to pre-soak lightweight aggregates before batching. Because water absorbed into lightweight aggregate is not factored into the water-cement or water-cementitious material ratios (*w/c* or *w/cm*), lightweight concrete initially contains a greater total volume of water than a normalweight concrete mixture with the same *w/c* or *w/cm*. Does this extra water result in delayed drying times?

Background

In 1998, Suprenant and Malisch[2] reported that a 4 in. (100 mm) thick, normalweight concrete slab took 46 days to reach a moisture vapor emission rate (MVER) of 3.0 lb/1000 ft^2/24 h (170 μg/(s · m^2)). In 2000, they reported that a lightweight concrete slab took 183 days to reach the same MVER.[3] In both studies, the mixtures had *w/c* values of 0.40, and the test slabs were manually finished and then cured by covering with polyethylene sheeting for 3 days. The slabs were then exposed to a controlled environment with 70 ± 3°F (21 ± 2°C) air temperature and 28 ± 5% relative humidity (RH).

A *w/c* of 0.40 is uncommonly low, curing times are generally longer than 3 days, and most slabs receive a machine-troweled finish. Slabs are also generally exposed to ambient conditions that can vary widely. So, what happens to the drying times of more typical normalweight and lightweight concrete mixtures, particularly when they are subjected to real-world ambient conditions with varying temperature and RH values? Flooring and adhesive manufacturers commonly expect concrete slabs to reach the 3.0 lb/1000 ft^2/24 h (170 μg/(s · m^2)) MVER or 75 to 90% internal RH before flooring can be installed.[4] Can a lightweight concrete slab be expected to reach these levels?

To help answer these questions, the Expanded Shale, Clay and Slate Institute (ESCSI) conducted a 13-month concrete drying study where normalweight and lightweight concrete drying times were measured in a nonconditioned environment in Dalton, GA.

In conjunction with RH testing equipment studies being performed by ASTM Committee F06, Resilient Floor Coverings, and concrete drying studies being performed by W.R. Grace, a follow-up study on the comparative drying of normalweight and lightweight concrete was conducted over a 7-month period. The follow-up study was performed in a conditioned environment at the W.R. Grace facility in Cambridge, MA, using temperature and humidity set points at 70°F (21°C) and 50% RH. Both studies are summarized herein and are covered in greater detail in a report available from ESCSI.[5]

Study 1: Nonconditioned Environment

Test slabs

Three 12 x 12 ft (3.6 x 3.6 m) test slabs were constructed on 2 in. (51 mm) deep formed fluted steel decking. The decking was elevated such that each slab had a minimum of 10 in. (254 mm) of air space beneath it (Fig. 1). The three slab assemblies were constructed to have 2-hour fire ratings per Underwriters Laboratories, Inc., Design No. D916.[6] Slabs 1 and 3 were constructed with lightweight concrete, and Slab 2 was constructed with normalweight concrete. Decking type and slab thickness values are listed in Table 1, and concrete properties are listed in Table 2. Both mixtures had *w/cm* of 0.5.

Fig. 1: Test slab formwork used in Study 1

Table 1:
Test slab parameters (refer to Table 2 for concrete mixture proportions)

Slab no.	Total slab thickness, in. (mm)	Concrete type	Steel deck type
1	5.25 (133)	Lightweight	Unvented
2	6.50 (165)	Normalweight	Unvented
3	5.25 (133)	Lightweight	Vented

Table 2:
Concrete constituent proportions and measured properties

Mixture type	Normalweight concrete	Lightweight concrete
Cement (ASTM C150 Type I)	469 (278)	460 (273)
Fly ash (ASTM C618 Type C)	80 (47)	80 (47)
Coarse aggregate (specific gravity = 2.74)	1840 (1092)	—
Coarse aggregate (expanded shale)	—	1075 (638) (18% moisture content)
Sand	1469 (872)	1480 (878)
Water	275 (163)	270 (160)
Density (at batch plant), lb/ft^3 (kg/m^3)	151.9 (2433)	122.8 (1967)
Dry density, lb/ft^3 (kg/m^3)	147.7 (2366)	111.7 (1789)
Slump, in. (mm)	3.5 (90)	5.5 (140)
Air content (at batch plant), %	1	5.5

Listed quantities are in lb/yd^3 (kg/m^3) unless noted otherwise

Both normal- and lightweight concrete mixtures were placed on June 13, 2007. Although the moisture content and slump of the lightweight concrete was suitable for pumping, the concrete was delivered to the test slabs by chute.

Immediately after the concrete was deposited, it was struck off with a dimension lumber screed and bull floated. When the concrete had hardened sufficiently to support foot traffic without indentation, it was machine floated and finished with a walk-behind power trowel. One half of each slab received a smooth, tight, but nonburnished finish. The balance of each slab received a burnished finish (Fig. 2). Immediately following finishing, the test slabs were covered with lay-flat polyethylene sheets. The sheets were left in place for a period of 7 days.

Test environment

Testing took place under a watertight roof in a large, nonconditioned warehouse. To simulate job-site conditions prior to complete close-in of the building, cross ventilation was provided by opening large warehouse doors on opposite sides of the building. Doors were opened daily during business hours and were closed at night and over the weekends.

Over the course of 13 months, the ambient temperature in the test area ranged from 99.5 to 47.6°F (27.5 to 8.7°C) (Fig. 3). Over the same period, the ambient RH in the test area ranged from 84.3 to 21.4% (Fig. 4).

MVER testing

Drying time measurements consisted of determination of MVER and internal RH. The MVER was measured in accordance with ASTM F1869-11, "Standard Test Method for Measuring the Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride." The internal RH was measured in accordance with ASTM F2170-11, "Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using in situ Probes."

MVER testing began 30 days following removal of the polyethylene curing sheets. Test kits were installed weekly for the first 12 weeks, at 2-week intervals for an additional 8 weeks, and at 4-week intervals for the final 32 weeks of the test. MVER tests were performed on both the tight troweled and burnished concrete areas. In each area, two tests were taken: one with the as-finished surface and one with the surface cleaned by grinding. After 30 days of drying, there was very little difference in the MVER results taken at the same time, regardless of slab finish or surface preparation method.

Ambient temperature and RH, however, had noticeable effects on the MVER. As listed in Table 3 and presented in Fig. 5, the MVER level for both normalweight and lightweight concrete reached the 3.0 lb/1000 ft^2/24 h (170 µg/(s · m^2)) emission rate required for many floor-covering installations only after 216 days into the study and when the ambient RH and temperature were at their lowest levels. The MVER levels returned above the 3.0 lb/1000 ft^2/24 h (170 μg/(s · m^2)) level as the ambient RH increased.

Internal RH testing

Sleeve-mounted RH sensors were installed into the three panels 28 days after the concrete was placed. In lightweight Slabs 1 and 3, sleeves were set at 40% of the slab depth (2.125 in. [54 mm] below the surface). In normalweight Slab 2, sleeves were set at 2.125 in. (54 mm) below the surface (to match the depth of the probes in Slabs 1 and 3) and at 2.625 in. (67 mm) below the surface (at 40% of the slab depth).

New sensors—each with a National Institute of Standards and Technology (NIST) traceable calibration certificate—were used for all measurements. The high initial humidity in the slabs caused several sensors to fail—these were replaced with new sensors as needed.

Internal RH measurements were taken manually on a weekly basis and using remote data-logging equipment on an hourly basis. For direct comparison, the in-place RH measurements shown in Table 4 are at the test depth of 2.125 in. (54 mm) for all three slabs.

While less noticeable than observed with MVER testing, the internal RH of the concrete was also found to vary with changes in ambient conditions (Table 4 and Fig. 6). As listed in Table 4, after approximately 90 days, there was no appreciable difference in the RH measurements between the burnished and nonburnished concrete finish for all test slabs.

Summary of observations in a nonconditioned environment

While the normalweight concrete test slab did dry to a lower moisture level than either of the lightweight concrete slabs, the differences were reasonably small. Also, it should be noted that in the 13 months that this study was conducted, neither the normalweight nor lightweight concrete recorded an internal RH level below 80% (Table 4).

Study 2: Controlled Environment

Test slabs

A standard normalweight concrete slab used as a control in this 18-slab study was identified as Slab 17 and was batched and placed at a *w/c* of 0.50 on April 16, 2009. The lightweight concrete slab used as a control in this study was identified as Slab No. 9. The lightweight slab was also batched and placed at a *w/c* of 0.50 using the same expanded shale lightweight aggregate that was used in the uncontrolled environment study in Dalton, GA, with a total lightweight aggregate moisture content of 23.6%. Slab 9 was placed on April 22, 2009.

Both slabs were placed over fluted metal decking (Fig. 7) and had equivalent fire ratings. The thickness of the lightweight concrete slab was 5.25 in. (133 mm) at the deepest part of the flute. The thickness of the normalweight concrete slab was 6.5 in. (165 mm) at the deepest part of the flute. Both slabs were cured by covering with polyethylene sheets for a period of 7 days (Fig. 8).

Drying of the slabs was measured using MVER tests per ASTM F1869 and internal RH tests per ASTM F2170. The

Fig. 2: Finished concrete surfaces from Study 1

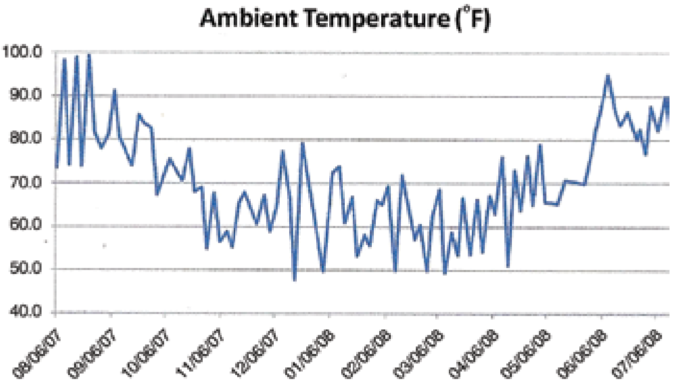


Fig. 3: Ambient temperature history for Study 1, Nonconditioned Environment; °C = (°F – 32)/1.8

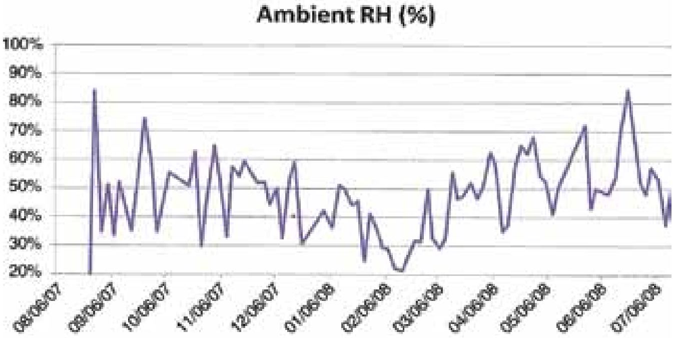


Fig. 4: Ambient RH history for Study 1, Nonconditioned Environment

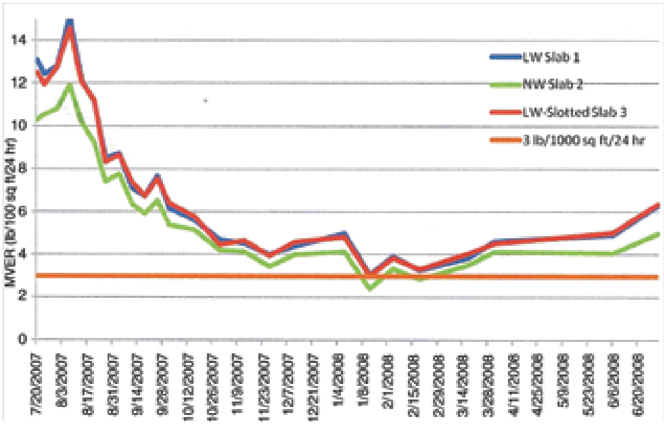


Fig. 5: MVER history for Study 1, Nonconditioned Environment; 1 lb/1000 ft²/24 h = 56.5 μg/(s · m²)

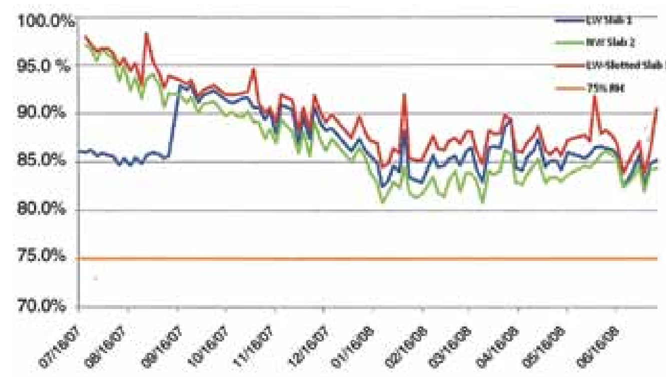


Fig. 6: RH history for Study 1, Nonconditioned Environment

Table 3:
MVER test results for slabs in a nonconditioned environment

Drying time, days	Ambient temperature, °F	Ambient RH, %	MVER results, lb/1000 ft²/24 h*		
			Slab 1 (lightweight)	Slab 2 (normalweight)	Slab 3 (lightweight)
30	76.0	62.0	12.3	10.3	12.7
48	85.0	74.0	15.7	12.6	15.5
90	74.7	60.0	7.9	6.5	7.9
174	65.4	41.0	4.9	4.0	4.8
216	53.3	29.0	3.2	2.6	3.2
281	66.1	38.1	4.4	3.5	4.4

*1 lb/1000 ft²/24 h = 56.5 μg/(s · m²)

°C = (°F – 32)/1.8

Table 4:
Internal RH and environmental extremes for slabs in a nonconditioned environment

Drying time, days	Final ambient temperature,°F	Final ambient RH, %	Final test slab temperature, °F	Internal RH, %					
				Slab 1		Slab 2		Slab 3	
				B*	F†	B*	F†	B*	F†
96	74.1	52.6	—	94.1	92.9	91.5	92.1	94.1	93.9
180	47.6	44.1	—	90.7	88.3	85.5	86.2	90.4	89.1
273	66.8	35.1	55.0	86.6	84.3	80.2	83.1	87.3	86.2
365	86.4	37.5	80.0	84.7	82.4	83.7	82.4	85.1	83.9
At maximum or minimum temperature or RH									
Maximum ambient temperature (99.5°F at 72 days)				89.1	84.8	93.6	91.6	94.0	92.9
Minimum ambient temperature (47.6°F at 180 days)				90.7	88.3	85.5	86.2	90.4	80.1
Maximum ambient RH (84.3% at 344 days)				87.2	85.8	85.9	84.4	87.2	87.1
Minimum ambient RH (21.4% at 219 days)				86.1	83.1	80.4	81.8	86.5	84.8

*Burnished

†Floated

°C = (°F – 32)/1.8

MVER tests were performed by W.R. Grace personnel. (It should be noted that, since the completion of the study, MVER testing in accordance with ASTM F1869 is no longer acceptable for lightweight concrete.) The in-place RH levels were recorded by representatives of a local consulting engineering firm.

MVER testing

The MVER test results for Slabs 9 and 17 are listed in Table 5. In nearly 7 months of the controlled-environment study, neither of the test slabs reached an MVER rate of 3.0 lb/1000 ft²/24 h (170 μg/(s · m²)).

Internal RH testing

One month after completion of the 7-day curing period, in-place RH sleeves and data-logger sensors were placed in both slabs at 40% of the slab thickness. Data from the sensors are presented in Table 6 and Fig. 9. While the normalweight concrete slab consistently exhibited a slightly lower internal RH level than the lightweight concrete slab, it should be noted that both slabs were still in the 85% RH range after 7 months of drying under ideal conditions.

Summary

The results of the two studies indicate that it can be a challenge to dry concrete slabs. Although the slabs fabricated with lightweight concrete took longer to dry than those produced using normalweight concrete, the difference in drying times in these studies is considerably smaller than has been previously reported.[3]

The observations match those we have made on construction projects across the country. Many slabs constructed with either normalweight or lightweight concrete are not drying sufficiently to meet the moisture levels required for installation of flooring materials within the allowable project schedule. So, unless many months of very favorable interior drying conditions are provided, it

Fig. 7: Test slab formwork used in Study 2

Fig. 8: Curing of test slabs for Study 2

Table 5:
MVER test results for slabs in controlled environment

Drying time, days	Ambient temperature, °F	Ambient RH, %	MVER results, lb/1000 ft²/24 h*	
			Slab 17 (normalweight)	Slab 9 (lightweight)
36	71.2	47.1	6.8	—
30	71.2	47.1	—	17.9
77	70.5	47.2	4.5	—
71	70.5	47.2	—	8.6
211	71.0	47.2	4.0	—
205	71.0	47.2	—	6.4

*1 lb/1000 ft²/24 h = 56.5 μg/(s · m²)

°C = (°F – 32)/1.8

Table 6:
Concrete internal RH at 40% slab depth

Drying time, days	Ambient temperature, °F	Ambient RH, %	Internal RH at 40% slab depth, %	
			Slab 17 (normalweight)	Slab 9 (lightweight)
96	73.4	65.5	92.1	—
96	74.1	67.6	—	94.4
180	70.5	47.6	87.9	—
180	71.1	46.9	—	89.6
223	71.6	48.4	85.0	—
229	71.6	48.4	—	86.4
273	71.6	37.8	—	80.6
281	71.6	34.2	—	79.9

°C = (°F – 32)/1.8

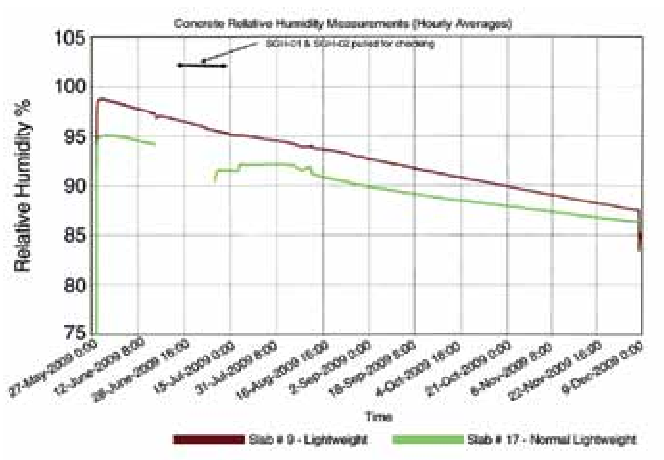


Fig. 9: RH results for normalweight and lightweight concrete slabs tested in Study 2, Controlled Environment

will be difficult for a concrete slab to reach the moisture levels currently required by many flooring material manufacturers and industry standards.

We believe that the benefits of lightweight concrete shouldn't be dismissed solely on the premise that switching to normalweight concrete will solve the concrete drying issue. Multiple factors influence the time necessary for concrete to reach an acceptable level of dryness, including *w/cm*, curing methods and duration, and ambient conditions. These factors should be given careful consideration at the design stage and throughout the construction process if either normalweight or lightweight concrete can be expected to dry to the levels currently required by the floor-covering industry.

References

1. Bremner, T.W., and Ries, J., "Stephen J. Hayde: Father of the Lightweight Concrete Industry," *Concrete International*, V. 31, No. 8, Aug. 2009, pp. 35-38.

2. Suprenant, B.A., and Malisch, W.R., "Are Your Slabs Dry Enough for Floor Coverings?" *Concrete Construction*, Aug. 1998, 4 pp.

3. Suprenant, B.A., and Malisch, W.R., "Long Wait for Lightweight," *Concrete Construction*, Nov. 2000, 2 pp.

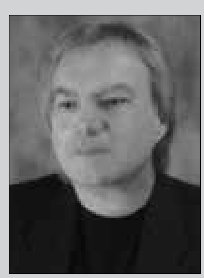
4. Kanare, H.M., "Concrete Floors and Moisture," Portland Cement Association, Skokie, IL, 2008, pp. 47-50.

5. Craig, P.A., "Lightweight Concrete Drying Study for the Expanded Shale, Clay and Slate Institute," January 31, 2011.

6. Underwriters Laboratories, Inc., Online Certifications Directory, Fire Resistance Ratings—ANSI/UL 263, Design No. D916, www.ul.com.

Note: Additional information on the ASTM standards discussed in this article can be found at **www.astm.org**.

Selected for reader interest by the editors after independent expert evaluation and recommendation.



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