Why won't the concrete dry?

The benefits of well-cured concrete don't apply to floors that must reach a low moisture-vapor emission rate before floor coverings are installed

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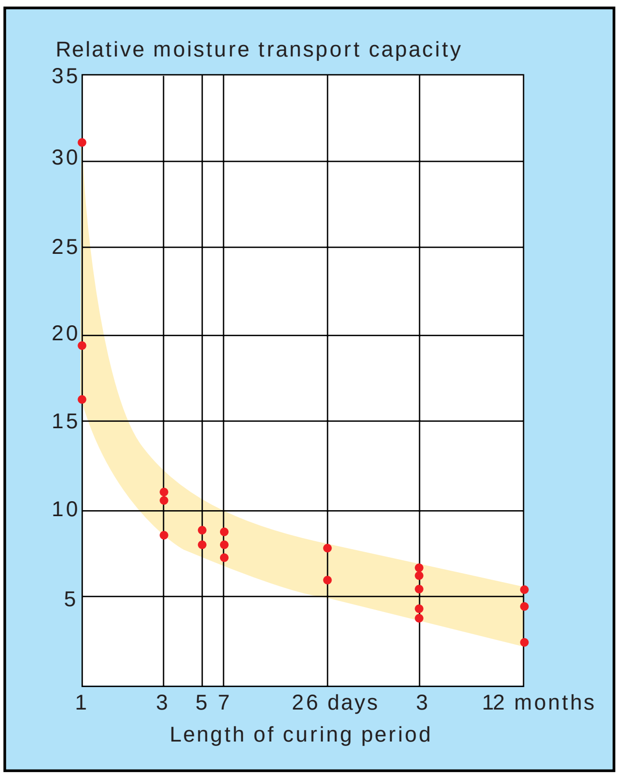
In September 1997, a general contractor placed a 5-inch-thick concrete floor directly on a vapor retarder. The design water-cement ratio was 0.54, and the contractor's crew added no water at the jobsite, keeping the slump of the 3500-psi concrete at a nearly constant 4 inches to aid in meeting flatness tolerances for the steel-troweled surface. Because the building wasn't enclosed until December and the fall weather was particularly rainy, the floor was continuously wet for nearly 3 months. After the building was enclosed, it was heated from December through March, and air-conditioning units were turned on in June.

In September 1998, the contractor called us for advice: "Why won't the concrete dry?" he asked. Although placed a year ago, with 9 months after building enclosure in which to dry, the floor was still emitting moisture vapor at a rate of 5½ to 6 pounds/1,000 square feet/24 hours. And the rate hadn't changed much in the past 2 months. Before the floor coating could be applied, however, the emission rate had to reach 3 lbs/1,000 sf/24 hrs.

We were stumped by the contractor's predicament. A reasonable water-cement ratio, no wet granular layer beneath the slab, excellent curing to bind capillary water in the hydrated cement paste, and a long drying period should have produced concrete that would quickly reach the desired moisture-vapor emission rate. But it didn't. Why?



The rate at which concrete loses moisture depends on how long the concrete cures. The longer the curing duration, the slower the water loss. Based on this test data showing the rate at which concrete specimens lose moisture, curing concrete for 3 to 7 days provides about the same rate of moisture loss, no curing about doubles the rate, and curing for about 3 months decreases the rate by about half.

How curing affects drying

Because cement hydration immobilizes some of the mixing water, well-cured concrete contains less free water that must evaporate before floor coverings can be applied. But well-cured concrete also has a disconnected void system that slows the moisture-vapor emission rate. So drying well-cured concrete requires removing a small amount of water, but that water must exit the concrete through a winding, constricted path.

In poorly cured concrete, where the duration of curing is short, the reverse is true. Less cement hydrates, so there's more free water. But the void structure of this concrete is more likely to be interconnected, resulting in larger pores that allow a higher moisture-emission rate.

Which curing condition is best if a contractor needs to install moisture-sensitive flooring as soon as possible? Results from several studies provide an answer to this question.

Table 1 Estimated drying time in days to reach 85% relative humidity

Duration of curing	Water-cement ratio 0.50	0.60	0.70
1 day	66	112	184
4 weeks	92	157	258

Note: Drying times are for 4-inch-thick concrete slabs drying from one side in a room at 50% RH and 70° F. The 85% RH is measured at a depth equal to 40% of the slab thickness. In the United States, moisture-vapor emission rates are measured instead of internal RH. Research conducted in 1965 found that 4-inch-thick specimens cured for 7 days and dried from one side at 73° F and 50% RH took 82, 117, and 130 days to reach 3 lbs/1,000 sf/24 hrs for water-cement ratios of 0.50, 0.60, and 0.70, respectively (Ref. 5).

More curing requires longer drying

Before moisture-sensitive floor coverings can be installed, Swedish specifications require the concrete's internal relative humidity (RH) to reach 85% or 90%, depending on the type of floor covering.

In one study, Hedenblad measured the time required to reach specified internal RH values at a depth equal to 40% of the slab thickness (Ref. 1). Based on that research, he developed a method for estimating drying time using correction factors to account for one- or two-sided drying and for variations in slab thickness, curing conditions, and temperature and RH during drying (Ref. 2).

Table 1 shows calculated one-sided drying times for concretes with water-cement ratios of 0.50 to 0.70 and moist cured for either 1 day or 4 weeks before drying began. Note that concrete with a water-cement ratio of 0.50 and cured for 1 day would reach 85% RH in about 66 days but would take about 92 days to reach the same RH if it had been moist cured for 4 weeks. For 0.70-water-cement-ratio concrete, the extended curing increased the drying time more than 2 months. More work by Hedenblad shows that when mature concrete is rewetted, it takes even longer to dry (see "When Year-Old Concrete Gets Wet").

These results aren't surprising. In a study of water-vapor conductivity through concrete and mortar, Wierig found that a 1-day wet curing period resulted in vapor conductivity about twice as high as that for a 3-day curing period, and as much as 15 times as high as that for a 365-day curing period (Ref. 3). Hedenblad found a similar trend (see graph on page **29**), showing that the ability of concrete to lose moisture declines continuously as the curing period lengthens.

Jackson and Kellerman conducted weight-loss tests showing similar effects of moist-curing duration on water loss (Ref. 4). The researchers placed mortar into metal pans to produce 6½ x12-inch specimens 2 inches thick. Some specimens were left uncovered, and others were covered with wet burlap for 1, 2, or 3 days before being allowed to dry from the top surface only in a room at 100° F and 32% RH. Table 2 shows the percentage of original mixing water remaining at ages up to 28 days. At 28 days, specimens that weren't cured had lost 41% of the initial mixing water while the specimens that received a 1- to 3-day burlap cure had lost only 19% or less.

Given the effect of prolonged curing on drying time, what curing duration should specifiers require for

Is no cure an option?

Howard Kanare, principal scientist and group manager for Construction Technology Laboratories, Skokie, Ill., tells of a construction project for which an uncured 4-inch-thick concrete slab with a water-cement ratio of 0.50 and a 4-inch slump achieved a moisture-vapor emission rate of 4 lbs/1,000 sf/24 hrs in only 4 weeks. "The floor was built under a waterproof roof and was placed directly on the vapor retarder," says Kanare, "so unreacted mixing water was the only source of moisture-vapor emissions."

He believes the no-cure regimen reduced the time needed to achieve the desired moisture-emission rate but worries that low strength at the concrete surface could cause a flooring-adhesive bond failure. "The surface of such poorly cured concrete, even when covered, also might deteriorate under wheel loads from heavily loaded gurneys or carts," says Kanare.

Results of laboratory studies reinforce Kanare's reservations about eliminating moist curing. Gonnerman found that air-cured concrete specimens showed a nearly 50% increase in wear over similar specimens moist cured for 2 days. To assess surface strength, he placed a ½-inch-diameter steel ball on the surface of test specimens and measured the force required to produce a ¼-inch-deep indentation. The required forces were 8,340 and 9,770 pounds for air-dried and 2-day-moist-cured concretes, respectively. Concretes used in both tests were 3 months old with 28-day compressive strengths ranging from 3500 to 4500 psi.

For floors that will receive moisture-sensitive floor coverings, Kanare recommends using plastic sheeting to cure the concrete for 3 days.

Reference

H.F. Gonnerman, "Study of Methods of Curing Concrete," *Journal of the American Concrete Institute*, February 1930, p. 359.

floors that will receive moisture-sensitive coverings?

Meeting schedules vs. achieving quality

ACI 308-92, "Standard Practice for Curing Concrete," recommends a 7-day minimum curing period for slabs on ground. Hedenblad's data show that reducing the curing period from 7 days to 3 days doesn't dramatically change the water-loss rate, but reducing it to 1 day does. Results from one project show that no curing is another option for speeding up drying (see "Is No Cure an Option?"). If the construction schedule requires floor-covering application shortly after concrete placement, reducing the curing period can help the contractor meet that schedule.

However, most designers are reluctant to specify a 1-day cure or no cure because this would reduce surface strength and abrasion resistance and increase shrinkage cracking and curling of the floor. Thus, the age-old tradeoffs between achieving quality and meeting construction schedules must still be addressed.

We know one thing for sure. When floors will receive moisture-sensitive floor coverings, curing periods longer than 7 days are unlikely to produce quality benefits that will offset the adverse effects on the schedule.

When year-old concrete gets wet

If new concrete loses moisture more slowly the longer it cures, how long does it take mature concrete to dry after it's rewetted? To find out, Hedenblad tested well-hydrated concrete specimens more than a year old. After rewetting the mature concrete specimens of different thicknesses and water-cement ratios were allowed to dry at 50% relative humidity and 70° F. The internal RH was measured at a depth of 40% of the thickness for one-sided drying and 20% of the thickness for two-sided drying.

Rewetted mature concrete with a water-cement ratio of 0.70 and drying from one side took 515 days to reach 85% internal RH. To reach the same RH level, newly placed concretes with the same water-cement ratio took 184 days when cured for 1 day and 258 days when cured for 4 weeks (Table 1).

This confirms the experiences of contractors who have had to repair flooded basements. When a basement floods, the mature concrete absorbs water and gives it up at a much slower rate. Removal and replacement of a moisture-sensitive floor covering in a flooded basement will probably require the use of a surface moisture barrier to limit the concrete's moisture-emission rate.

Reference

Goran Hedenblad, "Drying Times for Concrete after Water Damage" (English Translation), The Swedish Council for Building Research, 1993.

References

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3. Von H.-J. Wierig, "The Permeability of Cement, Mortar and Concrete to Water Vapor," *Zement Kalk Gips,* September 1965, p. 482.

4. F.H. Jackson and W.F. Kellerman, "Tests of Concrete Curing Materials," *Journal of the American Concrete Institute,* June 1939, p. 481.

5. Bruce A. Suprenant, "Moisture Movement Through Concrete Slabs," *Concrete Construction,* November 1997, pp. 879-885.

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Table 2 Percent of water remaining in specimens

Type of curing	Duration of curing: Hrs 3	Days 1	2	3	4	7	14	21	28
No curing	95	75	72	72	71	68	64	62	59
Burlap cure for 1 day		101	94	92	91	90	84	83	81
Burlap cure for 2 days			103	98	97	95	91	89	86
Burlap cure for 3 days				102	99	97	91	90	88

Note: Water remaining in specimens is shown as percent of original mixing water.
Specimens were 6½ inches wide, 12 inches long, and 2 inches deep.