

Design of Slabs that Receive **Moisture-Sensitive Floor Coverings**

Part 2: Guide to Specification Issues for Architects and Engineers

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When preparing construction documents for concrete slabs that will receive moisture-sensitive floor coverings, specifiers must consider both the benefits and liabilities of any decisions they make regarding:

- Vapor retarders;
- Concrete materials and properties;
- Concrete surface properties; and
- Protection of the floor surface.

The decisions require compromises—as do most design decisions.

VAPOR RETARDERS

Vapor retarder location is a critical decision, but material, thickness, and installation methods also must be considered.

Material

Most specifiers require the vapor retarder to conform to ASTM E 1745 “Standard Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular

Fill under Concrete Slabs.”¹ This standard requires specifications for vapor-retarder materials to include the following:

- This specification number (E 1745);
- Class A, B, or C, or alternatively, specific performance requirements for each of the properties (water vapor permeance, tensile strength, and puncture resistance); and
- Performance requirements, if any, for special conditions (flame spread, permeance after soil poison petroleum vehicle exposure, and permeance after exposure to ultraviolet light).

Class A, B, and C vapor retarders must all have the same 0.3-perm water vapor permeance but have to meet differing tensile strength and puncture resistance requirements. Class A has the highest strength and puncture resistance and Class C has the lowest.

Thickness

ACI 302.1R-96, “Guide for Concrete Floor and Slab Construction,”² gives the following recommendation for vapor retarder thickness:

“Although polyethylene film with a thickness of as little as 6 mils has been satisfactory as a vapor retarder, the committee strongly recommends that a thickness of not less than 10 mils be used. The increase in thickness offers increased resistance to moisture transmission while providing more durability during and after its installation.”

Tests confirm that a 10-mil thickness provides reasonable durability during and after installation when the vapor retarder is placed under a granular fill.³ When the vapor retarder isn't protected by a fill, some specifiers require a 20-mil thickness, or greater. Use of a vapor barrier instead of a vapor retarder may be appropriate when there is a risk of damage caused by construction traffic.

Location

Some specifiers require concrete to be placed directly on the vapor retarder. Others require placement of a

granular blotter layer between the concrete and the vapor retarder. Choosing a location that minimizes water-vapor movement may result in finishing delays and an increased chance of curling or cracking.^{4,5} Recently, ACI Committees 302 and 360 published a “Flowchart for Location of Vapor Retarder/Barrier”⁶ that is now a part of ACI 302.1R-96 (Fig. 1). Based on the flowchart, concrete slabs to receive a moisture-sensitive floor covering should be placed directly on the vapor retarder. The committee provides the following explanation:

“Based on the review of the details of problem installations, it became clear that the fill course above the vapor retarder can take on water from rain, wet-curing, wet-grinding or cutting, and cleaning. Unable to drain, the wet or saturated fill provides an additional source of water that contributes to moisture-vapor emission rates from the slab well in excess of the 3 to 5 lb/1000 ft²/24 h recommendation of the floor covering manufacturers.

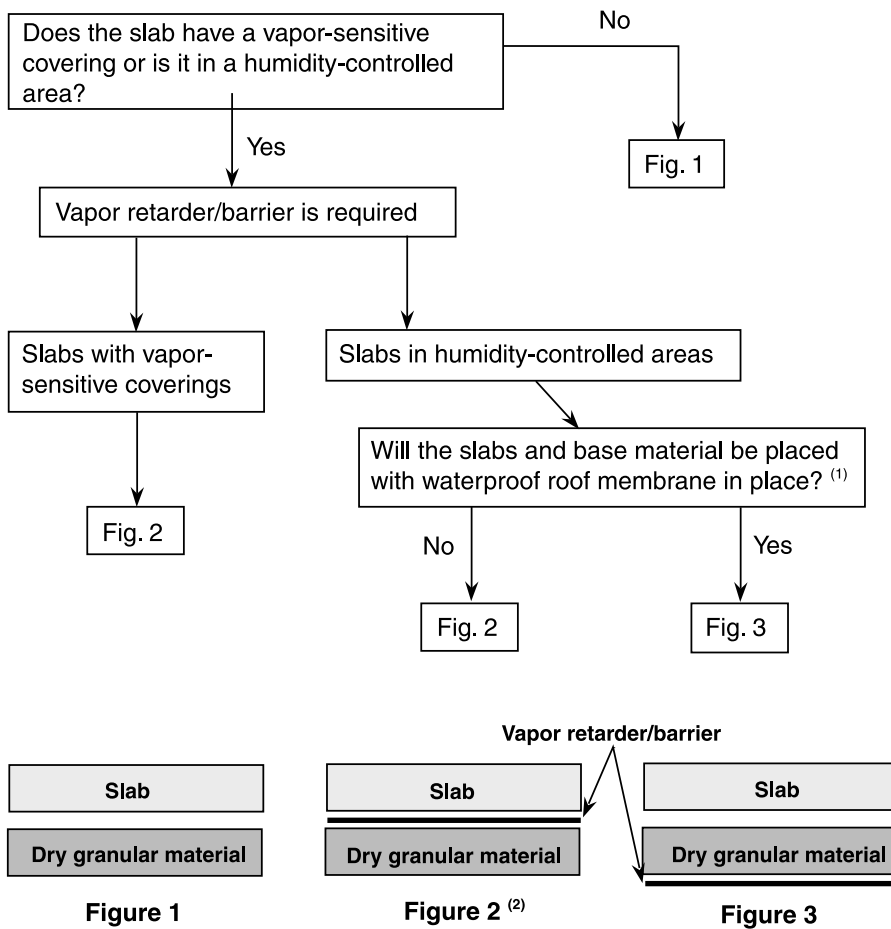
“As a result of these experiences, and the difficulty in adequately protecting the fill course from water during the construction process, caution is advised on the use of the granular fill layer when moisture-sensitive finishes are to be applied to the slab surface.

“The committees believe that when the use of a vapor retarder or barrier is required, the decision whether to locate the retarder or barrier in direct contact with the slab or beneath a layer of granular fill should be made on a case-by-case basis.

“Each proposed installation should be independently evaluated by considering the moisture sensitivity of subsequent floor finishes, anticipated project conditions and the potential effects of slab curling and cracking.

“The following chart can be used to assist in deciding where to place the vapor retarder. The anticipated benefits and risks associated with the specified location of the vapor retarder should be reviewed with all appropriate parties before construction.”

Some specifiers require placing the vapor retarder directly under the concrete slab even if initial plans for the building don't call for a moisture-sensitive floor covering. They reason that if such a floor covering is added in the future, there is no way to post-install a vapor retarder.



- (1) If granular material is subject to future moisture infiltration, use Fig. 2
- (2) If Fig. 2 is used, reduced joint spacing, a concrete with low shrinkage potential, or other measures to minimize slab curling will likely be required.

Fig. 1: Flowchart for Location of Vapor Retarder/Barrier (Ref. 6)

FLOOR-COVERING REFERENCE DOCUMENTS

Specifiers should be familiar with a number of ASTM standards and some other common references within the floor-covering industry. These references are sometimes cited in project specifications, but should be carefully read before they're cited. Some may not be appropriate for a particular project, and others may not contain up-to-date information. They can, however, often provide a reasonable method of delivering information to the contractor and product suppliers.

ASTM STANDARDS

- ASTM C 811-98 Practice for Surface Preparation of Concrete for Application of Chemical-Resistant Resin Monolithic Surfacing;
- ASTM D 4258-83 (reapproved 1999) Practice for Surface Cleaning Concrete for Coating;
- ASTM D 4259-88 (reapproved 1999) Standard Practice for Abrading Concrete;
- ASTM D 4260-88 (reapproved 1999) Standard Practice for Acid Etching of Concrete;
- ASTM D 4262-83 (reapproved 1999) Standard Test Method for pH of Chemically Cleaned or Etched Concrete Surfaces;
- ASTM D 4263-83 (reapproved 1999) Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method;
- ASTM D 5295-00 Standard Guide for Preparation of Concrete Surfaces for Adhered (Bonded) Membrane Waterproofing Systems;
- ASTM E 241-00 Standard Guide for Limiting Water-Induced Damage to Buildings;
- ASTM E 1643-98 Standard Practice for Installation of Water Vapor Retarders Used in Contact with Earth or Granular Fill Under Concrete Slabs;
- ASTM E 1745-97 Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill Under Concrete Slabs;
- ASTM E 1869-98 Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride;
- ASTM E 1907-97 Standard Practices for Determining Moisture-Related Acceptability of Concrete Floors to Receive Moisture-Sensitive Finishes;
- ASTM F 141-01a Standard Terminology Relating to Resilient Floor Coverings; and
- ASTM F 710-98 Standard Practice for Preparing Concrete Floors to Receive Resilient Flooring.

Other References

- CRI 104-1994 Standard for Installation of Commercial Textile Floorcovering Materials, The Carpet and Rug Institute, P.O. Box 2048, Dalton, GA, 30722-2048, (706) 278-3176.
- Addressing Moisture-Related Problems Relevant to Resilient Floor Coverings Installed Over Concrete, November 1995, Resilient Floor Covering Institute, 966 Hungerford Drive, Suite 12-B, Rockville, MD 20850, (301) 340-8580.
- Moisture Guidelines for the Floor Covering Industry, undated, World Floor Covering Association, 2211 E. Howell Avenue, Anaheim, CA 92806, (800) 624-6880.

Installation

Most specifiers require that the vapor retarder be installed in accordance with ASTM E 1643 "Standard Practice for Installation of Water Vapor Retarders Used in Contact with Earth or Granular Fill Under Concrete Slabs." Referencing this document requires the contractor to follow the manufacturer's instructions for placement (including laps and sealing around penetrations and foundation walls), protection, and repair.

ASTM E 1643 requires the contractor to use reinforcement supports that don't puncture the vapor retarder and to repair any damaged areas. Effects of holes in a vapor retarder have been measured.⁷ A 5/8-in.-diameter (16 mm) stake hole in 8-mil-thick polyethylene sheet over wet sand allowed a water-vapor emission rate of about 3.0 lb/1000 ft²/24 h.

CONCRETE MATERIALS AND PROPERTIES

There is much speculation—but not much published

data—about effects of concrete materials and properties on moisture-vapor emission. Two studies—Brewer⁸ in 1965 and Suprenant and Malisch⁹ in 1998—produced experimental data on concrete moisture emission. Brewer's moisture flow data were originally reported as grains/ft²/h but have been converted to a measure commonly used today—lb/1000 ft²/24 h.¹⁰

Brewer tested 141 specimens made from 29 different concrete mixtures that were moist cured for 7 days. Water-cement ratios (*w/c*) by weight ranged from 0.4 to 1.0. The 4-in.-thick (100 mm) concrete specimens were weighed as they dried with the following exposures: bottom sealed, bottom exposed to water vapor, and bottom in contact with water. As expected, concrete specimens exposed to water vapor or in contact with water dried at a much slower rate. Because it's recommended that for floors to receive moisture-sensitive flooring, concrete should be placed directly on a vapor retarder, this article reviews Brewer's data for bottom-sealed specimens.

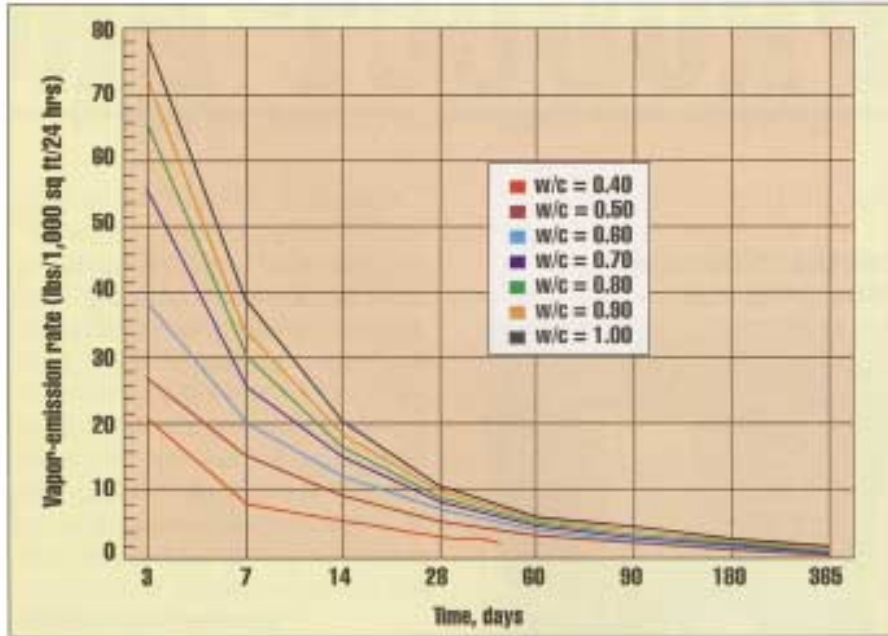


Fig. 2: The time required to reach a given water-vapor emission rate depends on w/c (Data from Ref. 8, converted to lb/1000 ft²/24 h, and from Ref. 9)

TABLE 1:
EFFECT OF w/c ON CONCRETE DRYING TIME

Drying time needed to reach 3 lb/1000 ft ² /24 h							
w/c	0.40	0.50	0.60	0.70	0.80	0.90	1.00
Days	46	82	117	130	148	166	190

Suprenant and Malisch tested 2-, 4-, 6-, and 8-in.-thick (50, 100, 150, and 200 mm), 3-ft-square concrete slabs made with w/c of 0.31, 0.37, and 0.40 and cured under plastic sheeting for 3 days. They measured water-vapor emission in accordance with ASTM F 1869, “Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride.”

Effects of admixtures and cementing materials

Brewer tested concretes with 300 to about 700 lb/yd³ (178 to 415 kg/m³) of ASTM Type I cement. Differing mixtures contained admixtures that included two air-entraining agents, two calcium chloride solutions, butyl stearate, and two water-reducing admixtures (lignosulfonate and hydroxylated carboxylic acid).

Suprenant and Malisch tested concretes with about 600 to 700 lb/yd³ (356 to 415 kg/m³) of ASTM Type I/II cement, a nonchloride accelerator, and a mid-range water reducer. One mixture contained Class F fly ash.

Neither study produced data showing that the presence of an admixture altered concrete drying or water-vapor emission rates. One of Brewer’s conclusions was that “...on the basis of concretes with equal water-cement ratios, the admixtures used neither contributed to, nor detracted from, the measured values to any appreciable degree.” On the other hand, Hedenblad found that using 10% silica fume by weight of cement could shorten drying time by about 2 weeks for a w/c of 0.45 and by about 4 weeks for a w/c of 0.50.¹¹

Hedenblad’s studies also produced test results showing that air entrainment, rapid hardening cement, and superplasticizers had little effect on concrete drying time.¹¹ He noted that “drying largely occurred in the same way as for concrete without superplasticizer admixture and with the same w/c ratio.”¹¹

Based on the available data, there is no reason to specifically include or exclude the use of any admixtures or high-early-strength cements as a way of influencing concrete drying or moisture emission rates. There is some evidence that concretes containing silica fume dry faster than concretes without silica fume.

Concrete properties

Brewer tested concretes with air contents between 1 and 7%, slumps from 1-1/2 to 8 in. (40 to 200 mm), densities from 139 to 154 lb/ft³ (2230 to 2470 kg/m³), and compressive strengths from 1300 psi to slightly over 8000 psi (9 to 55 MPa). Suprenant and Malisch tested concretes with air contents between 1.8 and 2.3%, slumps from 7 to 9-1/2 in. (175 to 240 mm), densities from 147 to 148 lb/ft³ (2350 to 2370 kg/m³), and compressive strengths from 7000 to 8000 psi (48 to 55 MPa).

Neither study produced data showing a relationship between measured concrete properties and concrete drying or water-vapor emission rates.

Water-cement ratio

Water-cement ratio has a significant effect on moisture migration through concrete slabs. Figure 2, derived primarily from Brewer’s original work, clearly shows that the time required to reach a given water-vapor emission rate depends on w/c . Table 1 shows the interpolated

drying time, in days, needed to reach 3 lb/1000 ft²/24 h for a 4-in.-thick (100 mm) specimen exposed to an environment of 73 °F (23 °C) and 50% relative humidity.¹²

Table 1 indicates that for concrete with a *w/c* of 0.40, a drying time of 46 days was needed to produce the commonly specified water-vapor emission rate of 3 lb/1000 ft²/24 h. This matched the drying time Suprenant and Malisch determined for concrete with a *w/c* of 0.40 and exposed to an environment of 70 °F (21 °C) and 28% relative humidity. They found no additional advantage in using concretes with lower *w/c*. Concretes with lower *w/c* dried at the same rate as concrete with the 0.40 *w/c*.

ASTM F 710, "Standard Practice for Preparing Concrete Floors to Receive Resilient Flooring," contains *w/c* recommendations in the Appendix (nonmandatory information):

"Moderate to moderately low water-cement ratios (0.40 to 0.45) can be used to produce floor slabs that can easily be placed, finished, and dried, and which will have acceptable permeability to moisture. Floor slabs with water-cement ratios above 0.60 take an exceedingly long time to dry and cause adhesives or floor coverings, or both, to fail due to high moisture permeability.

"A 4-inch thick slab, allowed to dry from only one side, batched at a water-cement ratio of 0.45, typically requires approximately 90 to 120 days to achieve a moisture vapor emission rate (MVER) of 3 lb/1000 ft² per 24 h (the resilient flooring industry standard MVER). The importance of using a moderate to moderately low water-cement ratio for floors to receive resilient flooring cannot be overemphasized."

Water-cementitious material ratio (*w/cm*) of 0.40 to 0.45 will typically produce concretes with compressive strengths of 4500 to 5000 psi (31 to 34 MPa). These strengths are likely to increase the potential for shrinkage, curling, and cracking. If a short concrete drying time is critical, a *w/cm* of 0.40 to 0.45 is needed. However, a concrete drying time of about 3 months is often suitable for construction projects. This time can be achieved using concrete with a 0.50 *w/cm*. Such a concrete is more economical, has enough paste for finishing, and makes it easier to satisfy other specification requirements related to surface finish and flatness. Water-reducing or mid-range water-reducing admixtures can be used to produce this concrete.

Requiring a *w/cm* of 0.50 is typically equivalent to requiring a specified compressive strength, f'_c , of 4000 psi (28 MPa). Don't specify a *w/cm* without specifying the corresponding compressive strength. ACI code requirements don't usually govern design and construction of soil-supported slabs, but the following quote from the code commentary should be noted:

"Selection of an f'_c that is consistent with the water-cementitious materials ratio selected for durability will help ensure that the required water-cementitious materials ratio is actually obtained in the field."

This indicates that compressive strength tests can be used to verify the *w/cm*. Field measurements of *w/cm* for fresh concrete aren't reliable enough for use in assuring that the specified value has been achieved.

Lightweight concrete

In addition to testing normalweight concrete, Suprenant and Malisch also tested a lightweight concrete with a *w/cm* of 0.40.¹³ Normalweight concrete with a 0.40 *w/cm* reached an emission rate of 3 lb/1000 ft²/24 h in 46 days. Lightweight concrete with a *w/cm* of 0.40 took 183 days to dry to the same emission rate. The test results for lightweight concrete were validated by field measurements for a structure in which the lightweight concrete took more than 6 months to dry.¹⁴ Specifiers should realize that obtaining the benefits of lightweight concrete may also result in significantly longer concrete drying times.

Slab thickness effects

A common rule of thumb for drying time has been "one month for each inch (25 mm) of slab thickness." Suprenant and Malisch measured changes in water-vapor emission values with time for 2-, 4-, 6-, and 8-in.-thick (50, 100, 150, and 200 mm) slabs of concrete with three different *w/cm* values.⁹ Regardless of the thickness, water-vapor emissions decreased at about the same rate. Based on these test results, reducing slab thickness won't reduce required drying times.

SURFACE PROPERTIES

Concrete properties at the floor surface affect two factors related to adhesive performance—moisture content and pH.

Curing effects

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 the disconnected void system in well-cured concrete slows movement of liquid or gaseous water. Drying well-cured concrete thus requires removing a small amount of water that must exit the concrete through a winding, constricted path. Which is preferred: a well-cured concrete with little free water but a difficult path to escape, or concrete with more free water that can escape through an easier path?

Experimental work by Hedenblad¹¹ and Jackson and Kellerman¹⁵ shows that less curing produces faster drying. Hedenblad's experimental work indicates that a 28-day cure instead of a 1-day cure increases the required drying time by about 1 month. Suprenant and Malisch¹⁶ and Kanare¹⁷ recommend using plastic sheeting to cure the concrete for 3 days. This provides a compromise between improving the concrete properties and decreasing the drying time.

Many specifiers require water curing for floors—sometimes as long as 28 days. This practice is counter-productive for floors that must dry before flooring materials are installed. It delays the start of drying, adds water that must later exit the concrete, and further constricts the path through which the water must exit. If drying time is critical to the schedule, don't specify water curing or curing times longer than 7 days.

Surface finish

When floors will receive coverings, most specifiers require a light power trowel finish with a light broom texture. Don't specify a burnished finish, as the surface will be too dense to be marked with a broom. Also, expect some wearing of the broom finish by the time the floor covering is applied.

There is some anecdotal evidence that concrete with a power-trowel finish dries more slowly than concrete without a power-trowel finish. In the troweling process, the surface is compacted and densified, apparently making it more difficult for water to evaporate. Where possible, consider specifying a bullfloat, straightedge, and broom finish.

Effects of pH

ASTM F 710 provides a summary of surface pH changes with age:

“As Portland cement hydrates, calcium hydroxide and other alkaline hydroxides are formed. The pH of wet concrete is extremely alkaline, typically around pH of 12 to 13. The surface of concrete will naturally react with atmospheric carbon dioxide to produce calcium carbonate in the hydraulic cement paste, which reduces the pH of the surface. Results in the range of pH 8 to 10 are typical for a floor with at least a thin layer of carbonation (approximately 0.04 inch).”

A totally carbonated layer of concrete has a pH of about 8.3.¹⁸ However, not all concrete will carbonate to a pH as low as 8.3. Measurements by several researchers indicate that the pH in the carbonated layer may drop to only about 10.5. The concrete slabs tested by Suprenant and Malisch had a pH of 9 after about 3 months of drying.⁹

A specified pH less than 10 may require acid etching. This is unlikely to be a good solution, as the acid must then be rinsed from the concrete surface. Adding rinse water rewets the surface and increases the needed drying time. Because of this, you should specify a floor-covering adhesive that is suitable for use with a substrate pH of 9 or 10 and doesn't require acid etching.

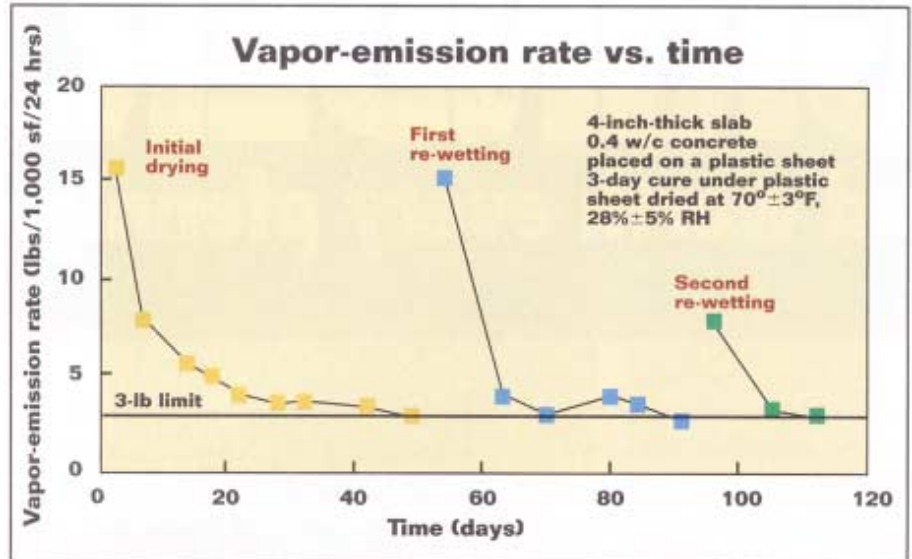


Fig. 3: Rewetting a slab after it has dried to the desired water-vapor emission rate requires further drying that will impact the construction schedule (Ref. 12)

Surface preparation

Regardless of the floor covering or adhesive manufacturer's instructions, no surface preparation should be allowed without authorization of the architect or engineer. ASTM F 710 states that “abrasive removal (shotblasting, sanding, or grinding) of a thin layer of concrete can remove [the] carbonated layer and expose more highly alkaline concrete below. Additional pH tests, waiting time, application of patching compound or underlayment, or a combination thereof, might be required after abrasive removal of the concrete surface.”

Unpublished test results by Suprenant and Malisch confirm this. They measured a pH of 9 on dried test slabs, then removed a thin layer of concrete surface by sandblasting. Measurements made immediately after the sandblasting yielded a pH of 12.

Some flooring manufacturers recommend cleaning or preparing the concrete surface by pressure washing. This adds additional water, and can raise the pH if some of the concrete surface is removed.

Most concrete slabs don't require surface preparation for the adhesive to bond. Tensile strengths of concrete surfaces often exceed 100 psi (0.7 MPa). Most floor covering adhesives, unless made with epoxy, pull off at 20 to 30 psi (0.14 to 0.28 MPa). Specifying a light broom finish should allow skipping the manufacturer's surface preparation recommendations. If there's a question about the effect of surface condition on adhesive bond, have a testing lab measure the tensile pull-off strength of the concrete surface and of the adhesive used for the floor covering.

Repairs

Concrete surface repairs can have an adverse effect on flooring-adhesive bond. If the repairs involve grinding

or shotblasting, the low pH could be lost. If the repairs involve the use of patching or underlayment materials, these need to dry after placement. Some floor repair products reportedly dry quickly, and may be useful for weekend repairs to existing facilities.

PROTECTION

When drying time is critical to the schedule, it's important to protect the slab from external moisture sources. External sources include rainwater, runoff from adjacent slopes, landscaping water, and water from curing or other construction activities such as wet-grinding, sawing, and cleaning.

Figure 3 shows the effects of rewetting on water-vapor emission rates. Low-*w/c* concrete took 46 days to reach an emission rate 3 lb/1000 ft²/24 h. Adding water to the surface after the 46-day drying period increased the emission rate to 15 lb, and five more weeks of drying were required to return to 3 lb. A second rewetting at this point increased the emission rate to 8 lb, after which it returned to 3 lb in 2 weeks.

Hedenblad found that rewetted mature concrete dries much more slowly than newly placed concrete.¹⁹ To simulate mature concrete, he tested concrete slabs that were more than a year old. Rewetted mature concrete with a *w/c* of 0.70—and drying from one side only—took 515 days to reach an internal relative humidity target. To reach the same internal relative humidity, newly placed concretes with a 0.70 *w/c* took 184 days when cured for 1 day and 258 days when cured for 4 weeks.

When drying time is critical and the moisture-sensitive floor covering is an important feature of the facility, the slabs should be constructed after the building is enclosed and the roof is watertight. Typically, this extends the construction schedule and increases costs, but these disadvantages must be weighed against a 1- or 2-month schedule delay that's likely if the floors are rained on.

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