

WHY ARE WE STILL HAVING PROBLEMS WITH MOISTURE AND CONCRETE FLOOR SLABS?

Good practices and excellent products are only the beginning to the solution

By Howard Kanare

Water is an essential ingredient in concrete, but uncontrolled excessive moisture can create a whole host of problems with concrete floor slabs. Some of the modes of distress include:

- Adhesive breakdown of adhered finish floor coverings
- Debonding of coatings
- Osmotic blisters of epoxy systems including coatings and epoxy terrazzo
- High pH (alkali) attack of floor finishes
- Microbial growths
- Flooring expansion, such as cupping of wood strips or planks
- Reactions between incompatible floor patching/leveling materials

Although the interaction of moisture and

floor finishes (adhered floor coverings and coatings) has gained much attention in recent years, moisture issues also affect bare concrete floors through the following modes:

- Staining
- Efflorescence
- Expansion of contaminants and popouts leading to further cracking
- Condensation on slab surfaces making hazardous conditions for traffic
- Curling

Despite the development of many excellent, longstanding practices, we continue to see a large number of moisture-related problems and hundreds of millions of dollars are still spent annually in the U.S. to correct such problems. Some contributing factors include: design profes-



Modern electronic thumb-size relative humidity probes now are available that can be placed below the surface of the concrete slab to monitor drying without interfering with construction or use of the floor. The devices provide real-time relative humidity and temperature at the push of a button. Photo: Howard Kanare

signals still specify a blotter/cushion/subbase layer over a vapor retarder—six years after ACI Committee 302 reinstated its original recommendation for slabs to be placed directly on the vapor retarder; vapor retarders are not carefully protected during construction; concrete floor slab mixes often are made with smaller than desirable aggregate and mixes are not optimized for minimum shrinkage; inappropriate moisture tests still are specified; moisture testing is not always done correctly; some unreasonably moisture-sensitive adhesives are still on the market; there is no performance specification or test method for moisture resistance of adhesives or floor coatings; and failures of some moisture-suppression products occur because there are no performance specifications for moisture suppression products. Let's look more closely at some of these continuing causes of moisture problems and how to avoid them.

VAPOR RETARDERS

This author firmly believes that a floor slab is part of the building envelope and that every slab on ground should have a vapor retarder meeting ASTM F1745 installed directly beneath the concrete. Just as we do not tolerate water leaks in roofs or walls, we should not accept structures

built so that moisture can infiltrate floor slabs. Highly moisture-resistant floors can be constructed following the principles in ACI 302.1R-06, "Guide for Concrete Floor and Slab Construction," and PCA EB119, "Concrete Floors and Moisture." A properly selected and installed vapor retarder is essential for long-term moisture resistance.

Vapor retarder material selection and placement was the subject of an extraordinary amount of debate during the 1990s. The original ACI 302-69, "Recommended Practice for Concrete Floor and Slab Construction," indicated vapor barriers are used under the slab when floor coverings, household goods, or equipment must be protected from damage by moist floor conditions.

In the years following, some field experience suggested that concrete placed directly on a low permeability vapor retarder was more prone to cracking and curling.

In the subsequent ACI 302.1R-89, "Guide for Concrete Floor and Slab Construction," the use of a blotter or cushion layer on top of the vapor retarder was first described. Vapor barriers were said to aggravate the problem of plastic and drying shrinkage cracking and should be avoided if ground moisture conditions permit. A granular, self-draining fill was recommended to act as a blotter over the vapor barrier.

In the ensuing decade, many floors built with this blotter/cushion layer construction detail suffered moisture-related failures. The many reasons for these failures are now quite well understood.

1. A 6-mil polyethylene sheet placed over granular subbase and covered with compacted granular material often sustains many punctures, rendering the vapor retarder ineffective.

2. Dampening the blotter/cushion layer to compact it adds significant water to the floor system. For example, 6% moisture in a 3-inch-thick cushion layer adds roughly 1½ pounds of water below every square foot of concrete. A concrete mix typically contains about 3 pounds of water per square foot of floor for a 4-inch-thick slab at 0.5 w/c ratio with 517 pounds of cementitious material (neglecting water in aggregate); thus, the minimal water in the cushion layer required for compaction increases the free water in the floor system by 50%, providing a long-term source of unwanted moisture.

3. The blotter/cushion layer can be exposed to precipitation and become exceedingly wet prior to concrete placement.

4. Compacted granular subbase fill typically has 10% to 20% void space. This space on top of the vapor retarder can act as a "plenum" for unwanted moisture intrusion over long distances. For example, water infiltration at the perimeter of the structure can travel with little resistance in this layer.

5. If the vapor retarder is installed intact, then it functions as a "bathtub" beneath the granular blotter/cushion layer. Liquid water or moisture vapor that gets into this layer after construction (e.g., pipe leaks, perimeter infiltration) cannot easily drain outward through the vapor retarder and therefore infiltrates and recharges the slab from below.

The commonly cited advantages of a blotter/cushion layer (less bleeding, shorter time to trowel, less plastic shrinkage cracking, reduced curling) can be achieved just as well by using well-designed mixes with properly graded aggregates and following ACI recommended hot weather concreting practices when necessary.

In April 2001, ACI Committee 302 published an update to this guideline, reverting to early ACI and PCA practice, recommending that concrete slabs be placed directly on vapor retarders if the slab will receive vapor sensitive floor covering. It is this author's opinion that all floor slabs should be constructed directly on an appropriate vapor retarder for the following reasons:

1. All finish flooring systems (wood, textile, resilient, hard surfaces, and polymer coatings) have some degree of moisture sensitivity.

2. Bare concrete floors can suffer from efflorescence and moisture accumulation that at least requires unanticipated maintenance and at worst may create slippery, hazardous conditions.

3. Omission of a vapor retarder permits continual movement of moisture into the occupied space of a building, increasing relative humidity.

4. Floor finishes are routinely changed during the life of a building. Even if the initial intention is to have a highly moisture tolerant floor finish in some areas (e.g., ceramic tile in cementitious thinset with cement grout), at some point in the future a more moisture-sensitive flooring product may be installed in that area.

5. Adaptive reuse of buildings, which were initially designed not to receive floor coverings (e.g., warehouses, big box retail stores), often requires a completely different and more moisture-sensitive floor covering to be installed for the new use.

6. Tenant buildouts of areas not originally intended for occupancy with finish flooring do receive moisture-sensitive finishes.

When concrete is placed directly on a vapor retarder, intimate contact develops between the top of the vapor retarder and the underside of the concrete slab. Moisture does not move horizontally between the concrete and the vapor retarder. Minor punctures or gaps in the vapor retarder may produce only localized effects instead of widespread moisture movement into a blotter/cushion layer. The vapor retarder directly under the concrete also acts to reduce friction at the underside of the slab, reducing the occurrence of random cracks due to restraint.

Vapor retarders should be specified to meet ASTM E1745-97 (2004), "Standard Specification for Water Vapor Retarders Used in Contact with Soil or Granular Fill Under Concrete Slabs." The Performance Criteria and Test Method table shows the three classes of vapor retarder recognized in the E1745. An ordinary 10-mil polyethylene sheet will meet the permeance requirements of the standard but may or may not meet the tensile strength and puncture resistance requirements. Most ordinary low-density polyethylene sheets

aren't certified to the standard. Design professionals should include a requirement in project documents that vapor retarders meet this standard. A number of products have been introduced in recent years to meet even the most stringent requirements of this standard.

In addition to specifications for the materials and placement of a vapor retarder, design details must be provided to ensure the integrity of the vapor retarder from wall to wall and around structural elements, such as columns and footings, and at all other penetrations.

MOISTURE TESTING

In recent years there has been a renewed interest and emphasis on moisture testing for concrete floor slabs. However, a minor proportion of all floors that should be tested actually are being tested before installation or application of floor finishes. Hopefully, new technologies will make floor moisture testing more economical and attractive to contractors and facility owners.

Electronic moisture meters have been available for several decades. They operate on principles of electronic capacitance or resistance and do not provide an absolutely accurate measure of the moisture condition of a concrete floor slab. They are useful as survey tools to evaluate comparative differences in moisture distribution across the floor. Most of these instruments are designed to read the upper approximately 1 inch of a concrete slab, avoiding interference from steel mesh or reinforcement within the slab. Therefore, these meters cannot indicate the moisture condition deeper in the slab.

The old plastic sheet test, ASTM D4263, has been found to be unreliable because it depends upon temperature and dew point at the concrete's surface. If the test is positive (dampness under the plastic sheet), then the floor is likely too damp to proceed with flooring or coating installation. However, a negative result under the plastic sheet does not necessarily indicate that the floor is sufficiently dry.

A major change is taking place in the way that the floor covering industry measures moisture in concrete floors. This change affects concrete floor contractors, general contractors, construction managers, owners, architects, and floor covering installers. Just as the concrete floor construction industry made the shift in flatness tolerances

from straightedge to the more appropriate, statistically based F_F/F_L system, now the floor covering industry is facing a major shift from measuring moisture vapor emission rates (MVER) to measuring relative humidity (RH).

The anhydrous calcium chloride test for MVER was developed in the 1940s as a qualitative evaluation of floor moisture condition. Without any documented scientific basis, it became a quantitative test in the 1960s. Now, nearly 500,000 MVER tests are performed each year in the U.S. In the past decade, we have learned that the test can be unreliable, capable of producing both false high and low results, and dependent on ambient temperature and humidity, water-cement ratio, use of lightweight aggregate, the presence of curing compound, how hard a floor was troweled, and how the test site is prepared.

Over the past 10 years, investigations of the MVER test method in the field and in the lab have found that it suffers from several serious deficiencies:

- The test has no pedigree: there are no published or existing data from the 1940s to 1960s that were used to establish the test kit dimensions, time of exposure, choice and mass of desiccant, or basis for calculations. There are no flooring performance data supporting the widely used 3-pound limit publicized in the 1960s (actually 2 pounds in the earliest printed versions), or the 5-pound limit for some products published by flooring manufacturers in the late 1990s.
- There is no practical way to calibrate MVER test kits. There are no standard reference concretes available with controlled MVER levels. Kit dimensions have been arbitrarily standardized to provide reproducibility between brands, but they are not absolutely "accurate."
- The test determines a portion of the free moisture near the surface of a slab, generally the upper 12 to 20 mm ($\frac{1}{2}$ to $\frac{3}{4}$ inches), providing no information about moisture conditions deeper in the slab.
- The test does not accurately determine the true MVER of concrete; it overestimates low moisture emission levels and underestimates high emission levels.
- Ambient conditions interfere with test results—warmer, more humid room air can yield higher MVER results even if the internal concrete moisture condition is unchanged. Floor surface preparation for

testing, such as gentle grinding, can change measured MVER drastically.

- Limits set for MVER based on product type—one level for sheet vinyl, carpet, or rubber, and a different level for VCT and felt-back resilient flooring—neglect the fundamental fact that adhesives play a major role in flooring performance.

Relative humidity for floor moisture measurement is not new—it was first used to measure moisture in concrete floors as part of Portland Cement Association's (PCA) applied research programs in CTLGroup's laboratories beginning in the 1950s. RH instruments can be independently calibrated directly traceable to national standards. There are a variety of commercially available RH instruments specifically for measuring moisture in concrete. Although RH instruments cost more than a calcium chloride MVER kit, large savings in testing time and labor are making RH the method of choice. More importantly, RH testing gives a much more useful picture of the actual moisture condition within the concrete regardless of mix, aggregate types, floor thickness, or surface conditions. Properly conducted RH testing can prevent premature flooring installation that can lead to costly repairs and litigation.

An all-too-common case in point: Several months after it was installed, sheet vinyl in a large, new hospital in Chicago was badly rutted and bubbled. Floors were tested before installation using calcium chloride kits and found to have about 4 lb/1000sq ft/24 hr MVER, below the flooring manufacturer's 5-pound limit for floor covering installation. However, after the flooring failure, RH tests indicated greater than 95% RH, well above the generally accepted 75% RH specified in ASTM F710. If RH testing had been done prior to installation, remedial action could have been taken to avoid the failure and the

expensive, disruptive repairs that must be done throughout this facility. However, the story is more complicated—some types of flooring in the building are performing fine while others are not. Two types of sheet vinyl exhibit failure while vinyl tiles and a third type of sheet vinyl are performing well. These observations indicate that different adhesives have varying moisture sensitivity and are critical to floor covering performance. Acceptable moisture levels should not be specified by flooring type (carpet, tile, or sheet) but should be based on actual system performance. CTLGroup has developed and implemented methods to evaluate performance of flooring system components at various, precisely reproducible moisture conditions.

RH has been the preferred method for assessing concrete floor moisture conditions in several countries for many years. Limits for installation range from 60% RH for direct glue-down wood parquet to 90% RH for some vinyl tile products. Flooring manufacturers in the U.S. must establish realistic RH limits for acceptable performance of their products through rigorous scientific testing, taking into account the various components of their systems, such as patching/leveling compounds, primer, adhesive, and floor coverings. Manufacturers will probably develop "tiered systems" that will allow design professionals and contractors to select flooring products for various moisture levels to produce enduring, successful outcomes.

REMEDICATION

If a floor is not dry enough when it is time to apply an adhered floor covering or coating, the owner and contractor have several options ranging from consideration of alternate finishes all the way to removal and replacement of the floor slab. What has become a fairly common approach is to isolate the moisture (and accompanying

high pH) of the concrete floor from the applied floor finish system. Two types of moisture barrier remediation systems are generally available: preformed membranes and liquid applied membranes.

Preformed membranes are available from several manufacturers designed for use under various types of finish floor systems such as carpet, wood flooring, resilient sheet, and hard surface tile. These products have very low moisture vapor transmission and therefore cause moisture to accumulate within the concrete floor slab below the membrane. This accumulation of moisture should not present a problem as long as the membrane is intact and sealed. There are no performance standards or prescription specifications for these products, so users must look carefully at their physical properties and compatibility with the intended finish floor system.

Liquid applied topical moisture vapor suppression systems are available in a wide variety of products including silicates, acrylics, epoxies, cementitious, and other materials. The products that provide the best resistance to water vapor transmission generally are high cross-link density, 100% solids two-part epoxies; some of these products when applied at 12 to 15 mils have water vapor transmission rates as low as 10 mg·hr⁻¹·m⁻², roughly as good as a 6-mil polyethylene vapor retarder sheet below the slab. Silicates may create a water-repellent surface, but they do little to suppress moisture vapor transmission. At this time, there are no performance standards or prescription specification requirements for these products. Manufacturers of some of these products also provide moisture-resistant adhesives to use in combination with the liquid membranes.

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For more information on relative humidity testing go to www.rapidrh.com