

CONCRETE SLAB-ON-GRADE MOISTURE TESTS:

HOW USEFUL ARE THE TESTING DATA WHEN THE VAPOR BARRIER MAY BE INEFFECTIVE?

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(Author's note: This article relies heavily on guidance found in ACI 302.2R-06, Guide for Concrete Slabs that Receive Moisture-Sensitive Flooring Materials, published by the American Concrete Institute, www.concrete.org, and the article "Take the Ground Out of Play!" by Peter Craig and Monica Rourke, published in the July 2008 issue of Interface. Close review of these highly informative publications is recommended for all construction professionals who may be asked to evaluate potentially problematic moisture levels at on-grade concrete – with or without floor coverings.)

Across North America, critical floor-covering performance evaluations of concrete slabs-on-grade often are supported by extremely limited data. It is not uncommon for decisions to install vinyl flooring or rubber-backed carpeting to be founded upon nothing more than the results of the "plastic sheet tests," or perhaps several "calcium chloride" tests, even though the widely respected authors of ACI 302.2R-06 report:

Although recognized as a standard practice for determining moisture-related acceptability of concrete floors by ASTM E1907 and by some manufacturers, the plastic sheet test does not give a reliable indication of the floor moisture condition. ...No laboratory data from a floor covering or adhesive manufacturer has been presented to establish a rational basis...

...for the moisture-vapor emission-acceptance limits commonly cited by flooring manufacturers for calcium chloride testing of concrete floors.

A similar warning is sounded by Peter Craig (a member of the committee that authored the ACI standard) and Monica Rourke in their highly informative *Interface* article:

Floor-covering, adhesive, and coating manufacturers publish concrete moisture limits for safe installation of their materials. Historically, the most common requirement was to

have the moisture vapor emission rate (MVER) not exceed either a 3-lb or a 5-lb level per 1,000 sq ft in 24 hours when tested in accordance with ASTM F1869. However, in recent years, the science of the calcium chloride test used to measure the MVER has become far better understood and the limitations of the test revealed. While knowing how much moisture is emitting from the slab surface can be helpful, the MVER test method does not detect the reservoir of moisture deeper in the slab that will rise to the slab surface once the floor is covered.

These warnings should not be construed as a blanket rejection of either of these test procedures. Instead, Craig and his fellow authors of ACI 302.2R-06 are striving to foster a basic understanding of concrete moisture and vapor-emissions tests and an intelligent appreciation of their uses and limitations.

ASTM E1907¹ identifies various procedures used in the building and flooring industries to evaluate moisture content (MC) or vapor emissions from concrete slabs, including four tests that are often encountered by construction professionals:

- The calcium chloride test is carried out in accordance with ASTM F1869², using a plastic dish containing anhydrous calcium chloride under a flanged, clear plastic cover sealed to the concrete. The dish is weighed prior to the test, and then, after a period of 60 to 72 hours, it is

weighed again. The current moisture vapor emission rate at this particular location is calculated with a formula that considers the increased weight of the calcium chloride, the test time, and the surface area inside the plastic cover.

- The polyethylene sheet test entails application of a plastic sheet to the surface of the slab for an extended period of time to ascertain if observable vapor condensation will occur under the sheeting. When moisture is present after the test, the concrete surface feels cooler and often looks darker. (This qualitative test is, of course, not limited to the use of plastic sheeting – any strongly vapor-resistant material can be laid upon a concrete floor to evaluate the potential for observable moisture condensation after several days, weeks, or months.)
- The electrical-impedance test uses a proprietary meter to determine relative-moisture content by sending an electrical signal into the slab. The depth of the signal penetration will vary (from 0.75 in to 2.0 in) depending on the material composition and MC of the slab.
- The internal relative-humidity (RH) test is carried out in accordance with ASTM F2170.³ Holes are drilled to a depth of about 40% of the slab's thickness to accommodate a tightly fit sensor that measures both the temperature and RH within the concrete. (For porous construction

materials such as concrete or wood, every combination of internal RH and temperature readings has an associated “equilibrium moisture content” value that increases with increasing RH and decreasing temperature.)

In short, the calcium chloride test and the plastic sheet method allow us to evaluate, at particular locations and particular points in time, the rate of moisture vapor emissions from the slab. The electrical impedance meter then allows us to measure MC levels near the slab’s surface, while the internal RH test enables MC readings from within the slab. Typically, concrete slabs without a floor covering have lower MC readings near the surface; in contrast, slabs with a vapor-resistant floor covering have MC levels that are nearly uniform throughout the concrete.

While these tests can provide useful informative data, the authors of ACI 302.2R-06 remind us, “Using multiple test methods...can result in potential conflicts when acceptable results are recorded with one test method but not with the other. For instance, the concrete internal RH tests may record an acceptable level when the MVER tests do not, or vice versa.”

Further, we are advised that the plastic sheet test should be used with caution because, depending on surface temperature conditions, the test can falsely indicate that a concrete floor is suitable for covering.

However, the plastic sheet test will not falsely indicate that a concrete floor is not ready for covering.

A key point made repeatedly by the authors of ACI 302.2R-06 is that we should not blindly rely upon limited testing data to predict successful long-term performance of moisture-sensitive flooring. Consider, for example, this writer’s flooring investigation at the ground-level offices of a two-story commercial building in Northern California with slab-on-grade construction and concrete tilt-up panel walls. The three-year-old building has large utility/storage spaces that have no carpeting and closely adjacent offices that were carpeted with 24-in-square rubber-backed carpet tiles attached to the concrete slab with latex adhesive.

Now, let’s assume that calcium chloride testing at the noncarpeted storage spaces has produced MVER results⁴ that would be deemed acceptable by floor-covering manufacturers (reference the above discussion of MVER quoted from Craig’s article in *Interface*). Further, an internal RH sensor installed into the concrete slab at a noncarpeted room (see *Photo 8*) registers only 72% RH, a value that may be acceptable to Craig and Rourke:

When a low-permeance vapor retarder is present directly beneath a thermally stable interior slab, and the concrete’s internal relative humidity measures 75% or lower at a depth of 40% of the slab’s thickness,

there is little chance of a flooring problem [occurring] that is related to moisture or alkali in the slab...

Are these seemingly satisfactory test results sufficient to allow us to predict the performance of the rubber-backed carpet tiles at the adjacent offices? In response, the authors of ACI 302.2R-06 would encourage us to not make this critical decision without careful consideration of the as-built slab design and the limitations of our moisture tests:

To ensure a reliable flooring installation, interpretation of test results requires a thorough understanding of the test methods, their limitations, and the slab design system.

In particular, Craig and his fellow authors of ACI 302.2R-06 would advise us that these various moisture tests are not reliable predictors of future flooring performance if the concrete slab has not been placed directly upon a functioning vapor barrier.

Without an effective vapor retarder/barrier directly beneath the slab, the results of any moisture test cannot be considered a true indicator of the moisture condition that will develop once the floor is covered.

Therefore, let’s consider a test cut (see *Photo 1*) of the concrete slab at the noncarpeted storage room. We find a 6-in concrete slab over a 3-in layer of compacted granular fill over two layers of 10-mil polyethylene over a layer of drainage material. Our first observation is that the concrete slab has not been placed directly upon the plastic vapor barrier. The authors of ACI 302.2R-06 warn us that this simple design decision, in and of itself, is sufficient to prevent us from trusting the results of our moisture testing as a predictor of successful long-term flooring performance:

Warning – A moisture test should not be used to predict future concrete drying behavior, to provide evidence that moisture criteria are satisfied, or to establish expected floor covering performance if the concrete slab has not been placed directly on a vapor retarder/barrier.

Further, as seen in *Photo 2*, numerous punctures in the polyethylene sheeting



Photo 1 – Test cut at concrete slab reveals compacted granular fill above the plastic vapor barrier and the granular drainage base.



Photo 2 – Polyethylene sheeting has numerous punctures, thus negating its usefulness as a vapor barrier.

have destroyed its usefulness as a vapor barrier, thus fully negating the predictive capabilities of our moisture-testing data:

Acceptance limits for surface moisture tests, such as the calcium chloride test, are established based on the assumption that a vapor barrier/retarder is present.

The purpose of this article is not to explore the pros and cons of the design and construction decisions made at this particular project. (These issues are being evaluated via the litigation process.) Instead, this writer's intention simply is to emphasize the warnings by the authors of ACI 302.2R-06 of the predictive limitations of moisture tests used at concrete slabs-on-grade not directly installed on a functioning vapor barrier:

For slabs not placed on a vapor retarder/barrier, the validity of any moisture test taken at the surface or with probes in the concrete should be questioned. The test result cannot be used to estimate the amount of water that

can move to the floor covering once it is installed, because the amount of water entering the bottom of the slab is impossible to determine.

Similarly, Craig and Rourke warn:

However, if a poor-quality vapor retarder has been used, omitted altogether, or placed below a fill-course layer that takes on water, any moisture-test result is subject to significant change, as moisture within the concrete will increase over time.

At this particular project, these warnings are graphically demonstrated by the



Photo 3 – Excess moisture has emulsified and deteriorated the water-soluble latex adhesives.



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Photo 4 – Excess moisture has emulsified and deteriorated the water-soluble latex adhesives.

Photo 5 – At all carpeted areas, the metered MC of the concrete surface exceeds 6.0%. (The orange cap covers an internal RH sensor, per ASTM F2170.)



accompanying photographs taken at the carpeted offices adjacent to the storage areas. As seen in Photos 3 through 7, exceedingly high moisture levels at the concrete floor resulted in failure and deterioration of the water-soluble adhesive used at the rubber-backed carpet tiles.

After reviewing these photographs, *Interface* readers and the authors of ACI 302.2R-06 will not be surprised to learn that calcium chloride testing carried out at the carpeted offices revealed very high rates of moisture-vapor emissions from the concrete slab. Similarly, internal RH sensors (see Photo 5) installed at these carpeted locations registered 99% RH, i.e., near-saturation conditions.

The authors of ACI 302.2R-06 also would not be surprised that these dramatic

failures occurred directly adjacent to noncarpeted locations where limited moisture testing produced seemingly satisfactory results:

For any moisture test, the acceptable moisture condition is based on the assumption that no water enters the slab from the bottom. Even if water that is initially present in the concrete moves from the bottom to the top of the slab, the resulting equilibrium MC at the surface is still assumed to be low enough to prevent a flooring failure. The results, however, will be different if moisture can enter through the bottom of the concrete slab.

In other words, floor-

covering systems that restrict vapor emission into the building interior will always cause some level of increased moisture at the surface of on-grade concrete slabs. The key to long-term success of these floor-covering designs is the efficacy of measures intended to minimize the migration into the bottom of the slab of additional moisture, which then leads to greater levels of trapped moisture at the surface. Common sources of such additional moisture intake include exterior groundwater and upward vapor diffusion from the water table below.

Compare Photo 8, taken at one of the storage rooms, with Photos 5 and 6. We see that the MC of the noncarpeted portions of the concrete slab also is unusually high, albeit significantly lower than at the adja-



Photo 6 – At all carpeted areas, the metered MC of the concrete surface exceeds 6.0%.

Photo 7 – Most of the failed adhesive is easily scraped from the wet concrete slab.



cent offices. If we had not already learned of the nearby flooring failure, this electrical-impedance test would have alerted us to a potential problem not identified by the calcium chloride and internal RH tests. Note that the authors of ACI 302.2R-06 advise, "More than one moisture test method may be needed to accurately determine the moisture-related suitability of a concrete subfloor, along with a thorough understanding of the slab design system."

An excellent introduction to the slab design, moisture movement, and flooring performance issues explored in ACI 302.2R-06 is found in Peter Craig's widely distributed article, "Vapor Barriers: Nuisance or Necessity?" first published in the March 15, 2004, issue of *Concrete Construction* magazine.⁵ Craig examines the sources of slab moisture, how moisture moves, and how it can adversely affect flooring materials, adhesives, and coatings. Further, he warns, "With the cost of floor coverings over concrete subfloors now estimated at more than a billion dollars a year in the United States, far greater attention must be given to the issue of moisture within and below concrete slabs on grade."


In particular, greater attention must be given to the informed use and the inherent limitations of moisture testing of on-grade concrete slabs. As long as some slab-on-grade floor-covering decisions still are based upon nothing more than a few calcium chloride tests – often by persons who have no direct knowledge of the as-built, under-slab, vapor barrier design – we should not be surprised by costly flooring failures and the litigation that often follows. The authors of ACI 302.2R-06 should be applauded for their efforts to break this cycle of failure. 



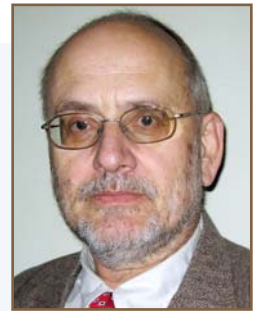
Photo 8 – At all noncarpeted areas, the metered MC of the concrete surface exceeds 5.0%. (The orange cap covers an internal RH sensor per ASTM F2170.)

REFERENCES

1. ASTM E1907, Standard Guide to Methods of Evaluating Moisture Conditions of Concrete Floors to Receive Resilient Floor Coverings, ASTM International, West Conshohocken, PA.
2. ASTM F1869, Test Method for Measuring Moisture Vapor Emission Rates of Concrete Subfloor Using Anhydrous Calcium Chloride, ASTM International, West Conshohocken, PA.
3. ASTM F2170, Test Method for Determining Relative Humidity in Concrete Floor Slabs Using In Situ Probes, ASTM International, West Conshohocken, PA.
4. Moisture vapor emissions rates of 2.2 and 3.8 lbs per 1,000 sq ft per 24 hours have been recorded at portions of the noncarpeted concrete slab.
5. A Google™ search reveals multiple Web sites from which Craig's article can be downloaded.

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