UTILIZING POLYMER TECHNOLOGY TO AVOID MOISTURE PROBLEMS

John Durig, President General Polymers Brand and
Tom Murphy, Vice President Marketing General Polymers Brand
The Sherwin-Williams Company
Cincinnati, OH 45249

Abstract

Moisture related problems for non-permeable flooring systems have plagued the construction industry for decades. Lower volatile organic compounds limitations and expedited construction schedules have increased the occurrences and awareness of the issue. This presentation will outline practices to prevent moisture problems regardless of the flooring system specified, remediate moisture issues during installation, and finally introduce a novel polymer chemistry that eliminates the problem.

Introduction

Understanding the cause of the moisture related flooring failure is the first step in treating and preventing a problem. For the most part polymeric floors are impermeable to moisture and can experience disbonding and blistering problems when water moves within a concrete slab after the seamless floor has been installed. Correctly specifying, installing and curing the concrete slab can prevent the problem. Because the flooring installer is generally not responsible for the concrete installation and may not be aware of how the slab was installed and cured, measuring the amount and emission rate of moisture from the slab is required prior to installing the floor. There are a number of remediation systems that have been recommended when moisture transmission rates exceed the flooring material manufactures requirements. Invariably this creates added installation costs and scheduling delays. Technology is now available which will not only meet aesthetics and performance requirements of the floor service conditions, but will also accommodate a variety of moisture emission conditions from a concrete slab.

Understanding the Problem

Seamless floors are generally comprised of polymeric materials which when cured have low permeability. Concrete slabs on the other hand are porous structures, which when untreated continuously allow moisture as a vapor to enter and leave the surface. Changing environmental conditions drive moisture vapor movement into or out of the slab. The movement of water must be controlled or stopped prior to sealing the concrete or the potential for problems will exist. This is complicated when flooring installations are conducted at temperature and humidity conditions that are different than when the building is placed in use. In facilities where temperature may experience daily or season changes, moisture within the slab will also be driven to cooler temperatures.

Direct sunlight on atrium floors changes the surface temperature and will affect moisture movement.

Fast track construction schedules, light weight concrete and high solids coatings have all played a part in contributing to moisture issues with non-permeable flooring systems applied to concrete. When concrete is initially placed the excess water must be allowed to evaporate before the non-permeable flooring system is placed. In a perfect world, the minimum amount of time required for the excess water to leave the freshly poured slab would be 28 – 30 days at a *constant* 70 degrees F (21 degrees C). In reality, temperatures vary and concrete may contain lightweight aggregates that hold water longer. Environmental consciousness has driven the industry to lower volatile organic compounds ("VOC") materials that perform differently than those containing higher percentage of solvents. High solids materials (low VOC) in general will not penetrate the slab as much, can be applied as thicker coatings decreasing permeability, and do not contribute to dehydrating the slab surface as much as solvent-born materials.

There are a variety of theories that explain the formation of blisters and disbondment of seamless polymer floors, the emulsification of tile adhesives, and the buckling of wooden floors. These theories include osmotic pressure, salt crystallization formation, high surface alkalinity, alkali silica expansive gel formation and mechanical bond interference. Although the mechanism of action varies among these proposed theories, the common element in all of these theories is the movement of water within the concrete slab. [1, 2, 3, 4, 5]

Movement of Moisture

Water moves in concrete as either a liquid of a gas. Liquid water will move into the slab from above driven by gravity. Liquid water will move from within or below the slab to the surface through capillary action or if below the water table by hydrostatic pressure. Water in a vapor form will move from a high vapor pressure to a low vapor pressure. This micro weather condition is driven by the interdependent relationship of humidity and temperature. At the same temperature, moisture moves from high humidity condition to low humidity conditions in an effort to equilibrate. At the same humidity, moisture moves from warm temperatures to cool temperatures. Warm air will hold more moisture causing water to condense on cool surfaces. Within a slab that is sealed with impermeable flooring system, the moisture drive is primarily related to the temperature differential, although slabs on grade will experience a humidity gradient through the depth of the slab.

There are several standard test methods used to measure the moisture in concrete and the movement of moisture from the slab. In theory, concrete that contains high moisture levels can experience a problem if the environmental conditions provide a motivation for the moisture to migrate. Standards that measure the emissions rate of the moisture provide a qualitative and quantitative picture of the movement of moisture. (Appendix A.)

The conditions during installation of the flooring system may also present a moisture related problem. In recent years industry experts have identified dew point as a contributing factor to water related flooring problems. A "dew point" condition is caused when the environmental conditions (humidity and temperature) trigger moisture from the air to condense within the cooler concrete surface. Generally, the condensation is not visible as the moisture is drawn into the porous concrete substrate. The moisture entering the surface of the concrete during this installation condition can present itself as a problem more rapidly than the more systemic moisture related causes.

Prevent the Problem

In new construction, the slab can be designed and installed specifically for non-permeable flooring. This process starts with preparing the soil-support system. Water is channeled away from the slab and is prevented from entering the slab. The recommended sub-grade would include 4 inches of crushed rock, 2 inches of sand and a vapor retarder. No additional sand is added on top of the vapor retarder! It is important to note that the spaces between granules in crushed rock are large enough to eliminate capillary flow, which makes this layer especially important in preventing the delivery of additional moisture to the slab.

ACI 302R requires the placement of the vapor retarder directly below the concrete slab when non-permeable flooring materials will be use. This vapor retarder minimizes moisture vapor migration into the slab from sources below. ASTM E1745 outlines the performance criteria required for vapor retarders. The permanence must be less than 0.3 perms as determined by ASTM E 96. In the past, 6 mils (0.15mm) of polyethylene film has been used as a vapor retarder. The standards outlined in ASTM E1745 require no less than 10 mils (0.25 mm). This increased thickness not only decreases the permeability but also provides greater durability during and after installation minimizing punctures and tears.

The volume of moisture that may pass through a slab is contingent upon the permeability of that slab. Permeability is governed by porosity, which in turn is a direct consequence of the water/cement ratio in the concrete mix design. As the water/cement ratio increases in linear form, the porosity and permeability of the concrete product increases exponentially. The water to cement ratio for concrete slabs to be finished with non-permeable floors must be less than 0.40. The concrete mix (Table 1.) should have no chloride salts. These salts can contribute to the amount of moisture retained in the slab after curing. In addition, moisture moving through the slab will carry these ions and hydroxides of calcium, potassium and sodium to the surface where they will concentrate. Utilizing well graded aggregate as specified by ACI C33 will help minimize slab voids and reduce the risk of problems associated with alkali silica reaction. During placement little or no additional water for convenience should be added.

Table 1. Concrete Specification Guideline

Cementitious Content (minimum)	517 lbs / yd^3
Water-Cement Ratio (by weight)	.40 - .45
Maximum size Coarse Aggregate	1 ½ inches
Air Content	4-6%
Slump (without high-range water reducers)	3 inches
Slump (with high-range water reducers)	6-9 inches
Compressive Strength (28 day)	5,000 psi
Permeability	LOW
Density	140 lbs. / ft^3

The concept of curing concrete is often mistaken for the process of drying concrete. Curing is the chemical reaction of cement with water to form a calcium silicate hydrate, the binder matrix for graded aggregates. The “curing” or hydration of concrete requires time. Over the first several days after placement, the concrete will have cured in excess of 90% but will continue to cure over the life of the slab. Wet curing during the first three to seven days after placement will maximize the hydration while minimizing the evaporation of water. This process, as with most chemical reactions is temperature dependent in cold conditions the curing process will take much longer than at higher temperatures.

Concrete is poured with an excess of 8-10 gallons of water per cubic yard in order to facilitate the placement of the concrete. Drying is the process of evacuating all of the excess water after the concrete has substantially cured. If the slab has not been adequately cured prior to drying, the evaporation process can form contiguous pores and capillaries within the concrete. Concrete that is highly porous facilitates the movement of moisture in the concrete slab.

The flooring installation specialty contractor understands that the issues with moisture problems and non-permeable floor systems are based upon the condition of the concrete. Whether it is a new construction project or a renovation of an existing building, the specialty contractor may or may not know if there is a moisture retarder below the slab, or what the water to cement ratio was during the initial placement. They must rely upon measuring the slabs moisture content, emissions rate and as much as possible, establishing controlled installation environment.

Treat the Problem

Prior to the installation of the non-permeable flooring system, an independent inspector or the flooring contractor may find that the slab does not meet the required standard of less than 3 pounds of water per 24 hours per 1000 square feet. This immediately presents a problem for the schedule and possibly the budget. There are options available to the owner.

1) Allow concrete to continue to cure, raise temperature and create an environment that takes the moisture out of the slab. If scheduling the installation is not time dependent, this "wait and see" approach can be the most economical.

2) If however, scheduling is a concern there is a proactive approach. Treat the concrete with the one of several remedial systems that densify the surface of the slab. Some of these systems also utilize a penetrating sealer that decreases the surface porosity and chemically react to form additional concrete paste. Most of these systems are comprised of a cementitious material that utilize the excess moisture and serve as a reservoir for any remaining moisture emitting from the slab. In all cases these types of systems require the confirmation that moisture emission rate is in compliance with the flooring materials specification prior to proceeding. Installation and subsequent testing can delay installations for several weeks.

3) Newer technology based upon urethane cement can be used independently as a remediation system or incorporated into the subsequent flooring system. This chemistry has an extensive history of success in the food and beverage industry. The thickness of the installation is critical to the success of the system performance. A minimum of 1/8

inch thickness must be applied in order to successfully prevent moisture problems for subsequent coating applications. The theoretical mechanism of action of this system is that it allows the moisture to move beyond the bond line. Moisture will permeate through the system, eliminating barrier at the slab bond line. This system requires no additional testing prior to applying a non-permeable flooring system.

4) Finally, the owner or specifier may opt to change the flooring system to one that is permeable and will allow moisture to migrate into the building. Although this will prevent issues with blistering or disbondment, it has not addressed the real problem of excess moisture moving through the floor. The excess moisture allowed to enter the building must be addressed with the HVAC system to prevent problems with other building materials or the growth of mold.

Eliminate the Problem

The newest technology available in seamless flooring utilizing a unique chemistry that combines the benefits of non-permeable epoxy flooring with the breathability of urethane cements. This material is based upon a novel water-based hardener. The reaction mechanism with epoxy resin forms an open three-dimensional architecture that will accommodate the movement of moisture vapor without sacrificing performance characteristics.

The specially designed hardener crosslinks with standard liquid epoxy resin for use in coatings, slurries, and mortar systems from 1 mm to 10mm thickness. This product is also used as the primer for these systems allowing the installation contractor to use one material for every application step of the flooring system.

The new technology has been formulated for application as a primer when reduced with 20% potable water. After standard concrete preparation [(6)] the low viscosity primer can be applied to dry or damp concrete. It penetrates the surface and rapidly (30-90 minutes) creates a film coat. When the concrete has severe out gassing issues, two coats of the primer are recommended. The quick recoat (1-2 hours) provides the applicator with the flexibility to adjust installations if unexpected condition presents themselves.

This same material can then be applied as a coating. Table 2 compares the typical properties of the new technology with a standard cycloaliphatic epoxy system. Even though the new technology is water-borne, there is no shrinkage when the system dries and cures. The Shore D hardness is slightly lower but comparable to standard epoxy. The natural finish is matt which corresponds to the higher coefficient of friction.

Table 2. Comparison of Physical Properties

	Novel Technology	Standard Cycloaliphatic Epoxy
Solids (%)	56%	90-100%
V. O. C.	Zero	0-20%
Hardness (Shore D) ASTM D 2240	80	85
Gloss	Matt	Glossy
Coefficient of Friction	0.28	0.15
Abrasion Resistance (C-17) ASTM D5178-91	156 mgs lost	138 mgs lost
Permeability (perm*cm) ASTM E96-95	1.44 x 10E-7	1.0 x 10E-9

Abrasion resistance is similar to standard epoxies with a slightly higher "milligrams lost" value as expected with higher coefficient of friction. Permeability as measured by ASTM E96-95 is over 100 times that of standard cycloaliphatic epoxy systems. Chart 1 compares the set times of standard epoxy with the new water-based technology. At both low temperatures and standard room temperature the water-based system sets more quickly allowing for faster installation and, in some cases, same day recoat.

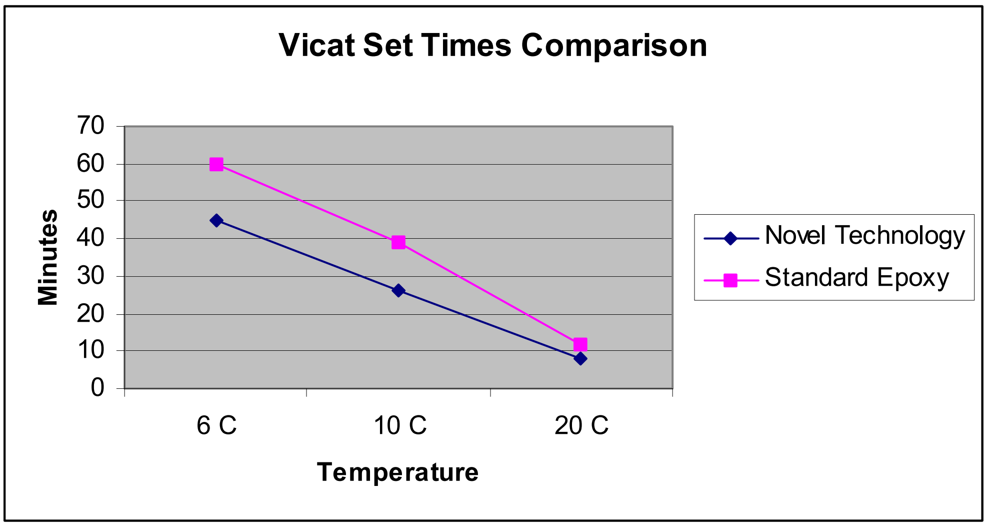

Chart 1. Vicat Set Times

The pot life of standard epoxy systems varies by formulation but generally provides the applicator less than hour of working time. The novel water-based epoxy maintains a low working viscosity for 2-3 hours. When the material exceeds it pot life the viscosity will rapidly increase. This is particularly important as compared with other water-based materials that will not change viscosity even though they have exceeded their pot life. This will potentially result in an installation that will not cure properly.

Benzyl alcohol is a common component formulated into many standard epoxy systems. This material is volatile and at high temperatures will cause standard epoxy systems to soften as measured by their Shore D hardness (Chart 2.). The new water-based epoxy systems contain no benzyl alcohol and outperform standard systems when exposed to elevated temperatures. This is particularly important in conditions where the flooring system will be exposed to steam cleaning or other continuous or cycled high temperature conditions.

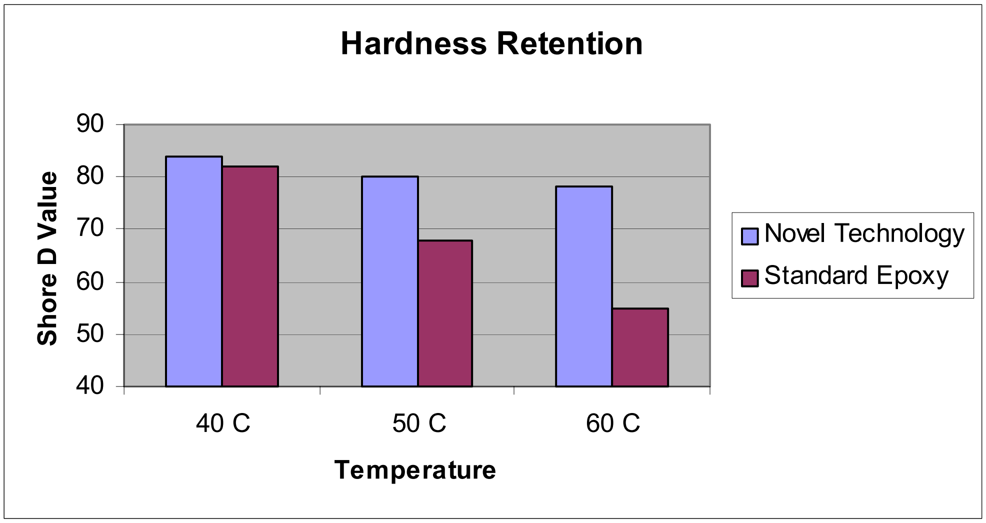

Chart 2. Hardness Retention

The UV stability of all epoxies is much lower than aliphatic polyurethanes. As measured using the Yellow Index the novel water-based technology has an initially higher yellow value than standard cycloaliphatic epoxy (Chart 3). After 10 days the novel water-based system has shown no change and Yellow Index for the standard aliphatic epoxy yields the same value as the novel water-based epoxy. The Yellow Index of the standard cycloaliphatic epoxy continues to increase throughout the test and is roughly double that of the water-base epoxy after 25 days. The novel water-base epoxy only shows a slight increase through the test period while the cycloaliphatic epoxy has increased three fold. This is primarily due to the fact that the novel water-based formulation contains no plasticizers such as benzyl alcohol.

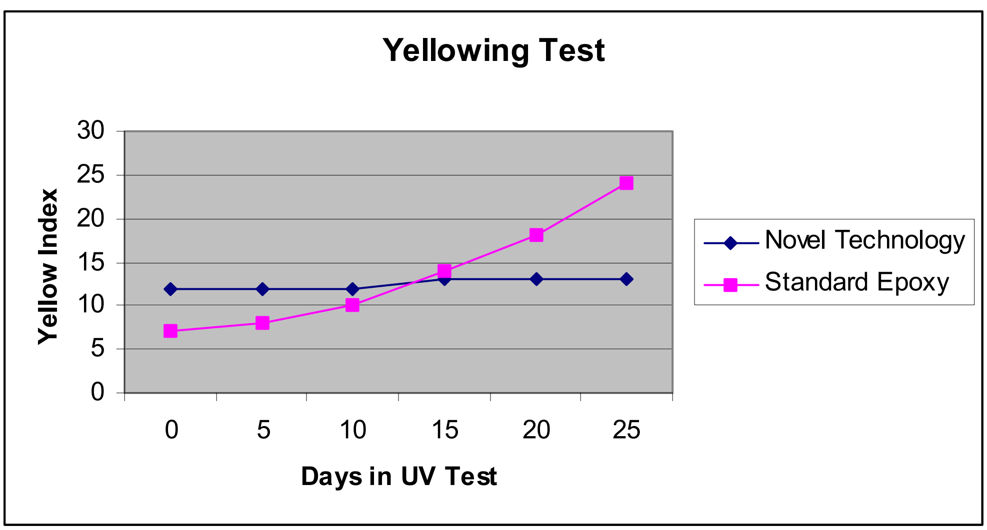

Chart 3. Yellowing Test

The chemical resistance of the novel water-based epoxy is good for water and some solvents but is not recommended for exposures to high levels of organic and mineral acids. The table below (Table 3) illustrated the affects of a seven-day chemical exposure (covered to prevent evaporation) on the test surface hardness. A softening may indicate a chemical attack, however the micro-pore structure of the novel water-based epoxy allows absorption of some chemicals such as ethanol, which are subsequently released without harm to the coating as illustrated by the recovery values. Standard epoxy systems do not recover as well from exposure to ethanol and toluene because these exposures extract plasticizers such as benzyl alcohol. Re-exposure of these floors may thus result in cracking (not shown).

Table 3. Chemical Resistance *(Percent Hardness as measured by Shore D)*

	Novel Technology		**Standard Epoxy**	
	7 Day Exposure	Recovery	7 Day Exposure	Recovery
Water	100%	100%	100%	100%
Ethanol	65%	100%	80%	85%
Toluene	100%	100%	85%	90%
1,1,1 Trichloroethane	85%	90%	90%	100%
10% Acetic Acid	40%	50%	85%	95%
70% Sulfuric Acid	80%	80%	85%	90%

For applications that require higher performance, aggregate is added to this resin to form self-leveling slurries and mortar systems. Self-leveling slurry systems are applied at 1/16 inch (60 mils) using 15 pounds of aggregate with a 1.25-gallon resin mix for each 50 square feet. This system will build to 1/8 inch (125 mils) using a full broadcast of 30-mesh silica sand. This system can be finished with the same novel water-based epoxy to yield a matt finish.

Mortar systems may be necessary in applications requiring thermal shock resistance or simply to resurface a badly worn surface. Using the same primer system and adding 75 pounds of specially formulated aggregate to 1.25 gallons of the water-based epoxy will yield 30 square foot of ¼ inch (250 mils) mortar application. Table 4 compares the typical physical properties of standard epoxy resurfacer, a urethane cement mortar and a system built using the novel water-based technology. All of these flooring chemistries provide excellent performance properties. The urethane cement systems generally have better chemical resistance and are much quicker to cure. The standard epoxy system generally require more time to install and have 10 times lower permeability than either the novel epoxy technology or the urethane cement systems.

Table 4. Comparison of Mortar Systems

	Novel Technology	**Standard Epoxy**	**Urethane Cement**
Working Time	2 hours	40 minutes	20 minutes
Recoat	12 hours	16 hours	4-5 hours
Traffic	12 hours	24 hours	10-12 hours
Impact resistance	> 160 in/lbs	> 160 in/lbs	> 160 in/lbs
Tensile Strength (28 days)	1,800 psi	1,900 psi	550-600 psi
Flexural Strength (28 days)	3,300 psi	4,000 psi	1,950 psi
Compressive Strength (28 days)	7,800 psi	9,000 psi	8,500 psi

In some cases, the specifier or owner may require a unique finish to the floor for added chemical resistance or for special color or gloss. As long as the new flooring systems is applied at 1/8 inch (125 mils) or greater and broadcast with 30 mesh aggregate, other traditional materials may be applied on the surface regardless of their permeability. Prior to applying these non-permeable materials, the water-based epoxy system must be allowed to fully cure for two days. Chart 4 shows a "worst case" water retention rate. This test was conducted using a slurry system applied to a steel plate so that all of the water was forced to leave the system through the surface. When applied the percentage of water (by weight) was roughly 15% of the total. After one day over 30% of the excess water has evaporated and greater than 90% of maximum evaporation is achieved by day 7. It is important to know that the ability to absorb water from the slab, while maintaining a strong and hard structure depends on the fact that the initial water must be allowed to leave the system, either through evaporation or into the substrate, prior to applying a non-permeable coating.

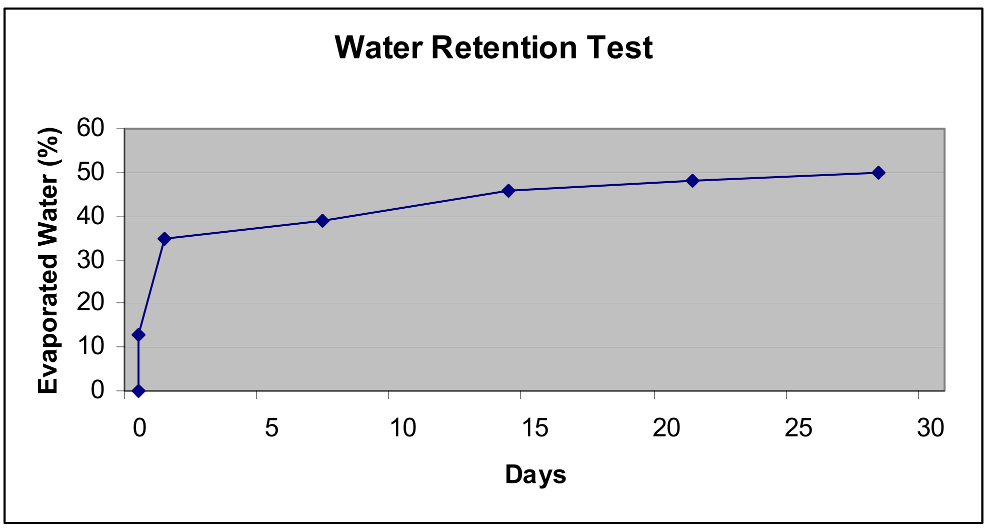

Chart 4. Water Retention Test

Decorative systems can also be designed with this material. After the primer application, a slurry coat is applied and broadcast with decorative quartz. A second broadcast can be applied using a standard clear resin system. A trowel-applied decorative system can be built with this chemistry substituting decorative aggregates for the mortar aggregate. In all cases, the moisture migration from the slab does not need to be measured, either prior to application or after installation of the novel water-based epoxy system.

Summary

Although we have a relatively good understanding of how to prevent, measure, and treat problematic moisture migration from concrete, problems continue to arise. The issue can be treated with specialized systems prior to applying the specified flooring system but this invariably creates construction delays and added costs. The solution is to eliminate the problem entirely using flooring systems that are not adversely affected by moisture migration. Novel flooring technologies are available that provide installation benefits, the performance required, and eliminate the issues related to moisture emissions.

References

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Appendix A. Moisture Measurement in Concrete

One of the simplest methods of determining if moisture is leaving the concrete slab is the ASTM D 4263 Standard Test Method for Indicating Moisture in Concrete by the Plastic Sheet Method. The plastic sheet is taped to the concrete a given period of time. If the concrete shows the presence of moisture or moisture condenses on the underside of the plastic, moisture is moving out of the concrete at those conditions. This qualitative method will indicate the presence of moisture movement, but it will not quantify the amount of moisture movement, and is only useful in determining that additional testing is required or if a flooring system that is not adversely affected by moisture vapor emissions should be used.

ASTM F 1869 - Standard Test Method for Measuring Moisture Vapor Emission Rate of Concrete Subfloor Using Anhydrous Calcium Chloride Moisture Emissions Test provides a quantitative evaluation of vapor emissions from the concrete. The floor and surrounding environment must be in the anticipated service condition for the test to provide a valid prediction of moisture movement after the floor is installed. The test must be conducted over raw exposed concrete that has been exposed to the environment for at least 24 hours. A quantitative evaluation is conducted wherein the anhydrous calcium chloride container & contents are pre-weighed on a gram scale, allowed to remain in it's container with the lid removed, and the container placed under a sealed dome to prevent loss of moisture for a period of 60 to 72 hours. Because concrete slabs are not homogeneous, three tests are required for the first 1000 square feet., with one additional test for every 1000 square feet or fraction thereafter. The container is removed and again weighed on a gram scale to determine the weight gain of the anhydrous calcium chloride. A calculation is performed to determine the amount of moisture adsorbed. These results are quantified as the rate of moisture vapor emissions expressed as pounds per 1000 square feet of surface area per 24 hours. Most manufacturers have adopted a value for application of polymer coatings or toppings to be not more than 3 pounds of moisture per 1,000 square feet per 24 hrs.

The plastic mat test and the calcium chloride test measure dynamic movement of moisture under the conditions at the time of the test. These conditions must be recorded with the results of the tests. Ideally, these tests should be conducted under the same conditions under which the flooring systems will be installed and maintained.

ASTM F 2170-02– Standard Test Method for Determining Relative Humidity in Concrete Floor Slabs Using *in situ* Probes, modeled after the European standard, requires drilling 5/8 inch holes in the slab to a depth equal to 40% of the slab's thickness. The hole is then lined with a plastic sleeve, capped and allowed to acclimate for 72 hours. The probe is placed in the sleeve, allowed to equilibrate for 30 minutes, and then readings are recorded. Acceptable relative humidity readings for substrates receiving non-permeable flooring vary by manufacturer and country standards but generally fall between 75% and 85%. Testing should take place in an acclimated building and is required to equal 3 tests in the first 1,000 square feet, with one additional test per each additional 1,000 square feet of concrete slab surface. This test method is less subject to conditions occurring at the concrete surface that may influence calcium chloride test results. This method only defines existing moisture content of the slab and does not address moisture vapor emissions.