Measuring and Removing Moisture in Concrete

Before you coat concrete, you need to know how much moisture it contains and how to remove the excess moisture.

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(above) Santa Theresa Water Treatment Plant, Santa Clara, CA
Photo courtesy of Munters Corporation, Moisture Control Services

When protective coatings are applied to a steel substrate, there are a few basic rules to follow while preparing the surface to assure good adhesion of the coating throughout its expected service life. Our industry has clearly defined cleanliness standards and standards for the surface profile required for various coating types. When these very measurable parameters have been met and the surface is free of contaminants, the coating can be applied with predictable results.

With concrete surfaces, however, what is occurring below the surface is also a consideration. Excess moisture is the cause for a large percentage of the coating failures on concrete. The configuration and structural integrity of the concrete slab must also be considered. Cracks, control joints, and expansion joints must be addressed properly. The potential for corrosion of the reinforcing steel must be considered, and the designers and builders must assure that moisture is not allowed to penetrate the concrete structure from the ground side.

Some of the characteristics of the concrete itself should be considered when choosing a coating type, scheduling the project, and planning the pour and application. These considerations include cement ratio, pH, compressive strength, permeability, contaminants below the surface, surface moisture, and moisture content.

This article will focus on the issue of moisture content. It will discuss the methods that are used to measure the moisture found in a concrete structure and how excess moisture can be removed.

Methods Used To Measure Moisture in Concrete

The Plastic Sheet Method[1] (ASTM D 4263)

As the most familiar method for determining if the concrete is ready to coat, this method has rescued many coating applicators from disaster. It is a "go, no-go" test in that if moisture is detected, the concrete is probably not ready for coating.

In this test, an 18-inch x 18-inch (450-

millimeter x 450-millimeter) square of clear plastic sheet is sealed to the surface with tape on all 4 sides. If, after 16 hours, any condensation is found on the underside of the plastic or if the surface of the concrete is darkened, the concrete is considered too wet for coating application. In cooler conditions, the concrete may retain its moisture and fail to condense on the plastic. However, an obvious appearance of moisture in this method almost always indicates excessive moisture.

The standard also warns against allowing the sheet to come in contact with direct sunlight or excessive heat. It is recommended that the surface temperature and ambient conditions be within the established parameters for application of the coating system. The reliability of the results of this test can be influenced by differences in the temperature of the plastic sheet.

The plastic sheet method of measuring moisture is a quick, easy, non-destructive, and inexpensive way to indicate excess moisture. It does not, however, provide any quantitative results, and it can easily result in a "false positive" impression, failing to alert the applicator of an excess moisture condition.

Relative Humidity (RH) Test[2,3]

Another non-destructive method for measuring moisture in concrete uses an instrument that measures relative humidity under a sealed chamber at the surface of the concrete. This method allows you to quantify changes occurring as the concrete dries and produces a quantifiable reading of the moisture content.

The test is performed by sealing an insulated box to the concrete and measuring the relative humidity inside the box with a calibrated capacitance-based humidity gauge. If the concrete is at 5 percent moisture content, it will neither absorb nor desorb moisture if the air above it is 70 F (21 C) and 75 percent RH. Therefore, if the air inside the box measures less than 75 percent, it can be assumed that the moisture content of the concrete is less than 5 percent. With the use of an insulated box, the air inside will assume a relatively stable dry bulb temperature close to the temperature of the concrete. It is necessary to let the air in the box stabilize for 16 to 24 hours before taking a reading.

Using relative humidity above the surface offers another non-destructive method of measurement at a relatively low cost. This method is also easy to use and, unlike the sheet method, the results are quantified. When performed properly with calibrated instruments, the test can yield accurate, repeatable readings. When a coating manufacturer specifies a maximum moisture content in a percentage, this method will allow an applicator to insure that the concrete is within tolerance.

A variation of this method has been used to measure the content deeper in the concrete. A hole is drilled and a plastic plug is placed in it. The probe of the humidity gauge is inserted into the plug and left to stabilize. RH readings are then taken

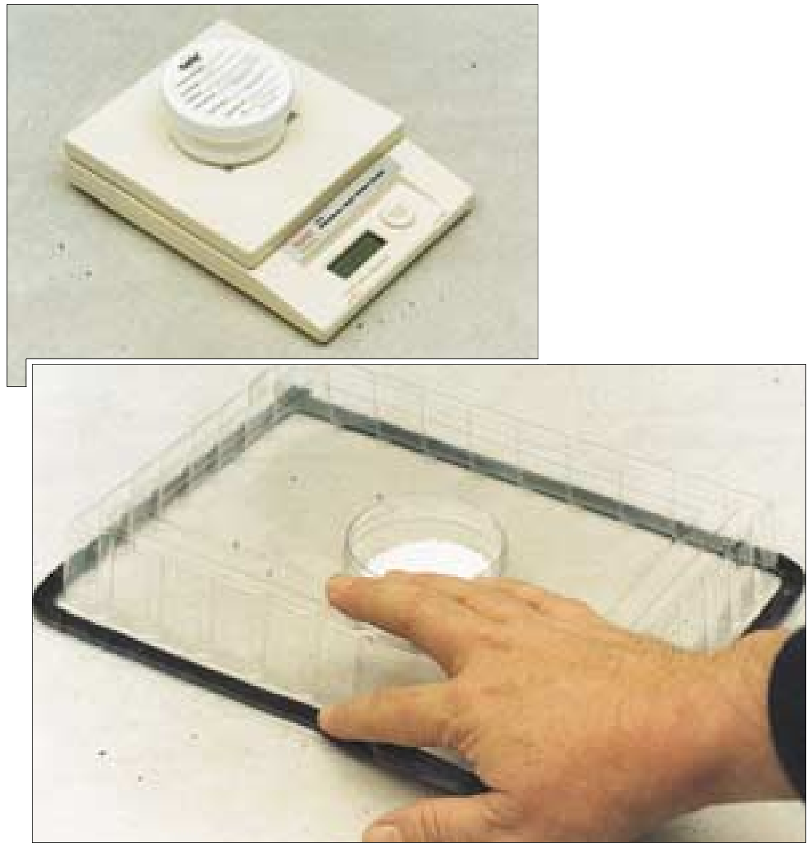

Fig. 1 - Calcium chloride test
Courtesy of Taylor Tools

as they would be in the insulated box. The advantage of this variation is that the measurement is not affected by surface sealers, curing agents, or coatings on the concrete. Heat generated by the drilling will dry the concrete around the hole. Therefore, the concrete around the hole must reach equilibrium with the rest of the concrete before an accurate reading can be taken. The many hours that this could take can present a limitation on this variation.

Calcium Chloride Test

It is also possible to measure how quickly moisture is escaping a concrete structure. This is important to the performance of many coatings and floorings because they cannot tolerate much vapor transmission before they begin to blister or disbond. Vapor transmission measurement is also meaningful when solving chronic problems in existing structures where high water tables or poor vapor barriers may affect coating performance.

The common method for measuring vapor transmission uses a small dish of calcium chloride placed on the surface and covered with a larger, impermeable clear cover. The known quantity of salt is weighed after 72 hours and compared to its original weight to determine the moisture gain (Fig. 1). The results reflect the rate at which the moisture is desorbed from the concrete, expressed in pounds of water per 1,000 sq ft (kilograms of water per 90 sq m) per 24 hours.

After it has spent its allotted time absorbing moisture from the floor, the calcium chloride is normally purchased in a sealed container and returned to a lab for weighing. This method offers excellent documentation at the cost of time and overnight mail.

Extremely wet floors can exhibit vapor transmission readings over 10 lbs/1,000 sq ft/24 hrs (4.5 kg/90 sq m/24 hrs), and values up to 22 lbs/1,000 sq ft/24 hrs (9.9 kg/90 sq m/24 hrs) have been found. A value of 3 lbs/1,000 sq ft/24 hrs (1.4 kg/90 sq m/24 hrs) or less is believed to be acceptable to most flooring and coating manufacturers.

Two common instruments are used for spot readings to determine patterns in drying progress or relative readings throughout a structure.

Gel Bridge Test

Like many materials, concrete has the ability to conduct electricity. The electrical conductivity of a masonry material is increased as moisture is added.

Therefore, if the conductivity of dry concrete is known, we can determine how much moisture is in the concrete by measuring its actual conductivity. A higher electrical conductivity indicates a higher moisture content. Several instruments on the market are designed to measure conductivity in building materials.

These instruments are used in several ways. The most accurate test involves drilling holes into the concrete and filling them with conductive gel. Two metal pins or nails are then set in the holes. Electrical conductivity is measured through the concrete bridge between the gel, acquiring its name—gel bridge test. More often, 2 sharp spikes mounted on a single probe are driven into the surface to get the conductivity reading at the surface (Fig. 2).

Although this is a fairly accurate method of measurement for drywall or known species of wood, where the exact makeup of the material is known, poured concrete is not nearly as consistent. Concrete's conductivity is affected by voids, concrete mix ratios, aggregate type, and aggregate size between the pins or spikes. Because it is impossible to know what is actually between the pins, the readings obtained from these instruments are relative, rather than absolute, determinations of moisture content.

Radio Frequency Test

Radio waves are absorbed by water molecules. There are devices now used to transmit and receive a radio wave passed through the concrete (Fig. 3). The moisture content is then determined by how the wave is absorbed. These instruments offer the fastest means of assessing the speed of the drying process. As in the gel bridge test, the content and aggregates in the concrete will affect the readings. Manufacturers of the devices provide tables to compensate for different aggregates; however, details of the pour and the mix are rarely available.

Radio frequency instruments can be very useful as a reference to locate areas that are wetter than others or to determine relative moisture content. For example, many surface readings can be taken quickly to compare other areas of a structure to a sample of a known moisture content.

Considerations When Measuring Moisture

Any type of sealer or curing compound on the surface can interfere with all of the non-destructive moisture tests. These surface treatments can also interfere with the adhesion of coatings. Most coating manufacturers will recommend that the treatments be removed before the coating application.

It is important to distinguish between vapor transmission and moisture content. You may have an acceptable moisture content in the concrete and encounter a failure later due to a continued vapor transmission through the slab. With a cold slab, you may experience a low level of vapor transmission from a moisture-laden concrete structure. Both scenarios would warrant the application of 2 types of testing to determine whether the concrete is ready to be coated.

For effective and accurately documented results, at least 2 measurement techniques should be used. The results can then be compared for accuracy. Two methods that complement each other well are the radio frequency method and the calcium chloride method to verify accuracy and provide documentation. As an added benefit, both are non-destructive.

When Do You Have a Moisture Problem?

Surface moisture can inhibit initial cure and coating adhesion. By acting as a bond release, surface moisture can affect adhesion much as condensation affects adhesion on a steel surface. Rather than adhering to the substrate, the coating adheres to the water or displaces it to get to the surface below.

When moisture in the concrete migrates to the surface or tries to escape after the coating has been applied, it can cause bubbling or "fish eyes" in the coating. This is a form of what is called outgassing and normally occurs as the concrete is warming. After the coating has cured, trapped moisture can cause coating disbondment as the moisture migrates to the surface and out of the concrete. These vapor drive forces are very strong and can exceed the adhesion strength of the coating and the tensile strength of the concrete.

Water will migrate to the surface when there is a higher vapor pressure in the concrete than in the air above the surface. This condition is common when a flooring is applied in a new building before the air conditioning is activated. As the building stabilizes, the air conditioning lowers the vapor pressure in the building while moisture condenses out of the air.

Coating manufacturers have discovered effective methods of overcoming adhesion problems on damp concrete surfaces with the use of various penetrating primers. Most manufacturers will agree, however, that a dry surface will certainly improve adhesion. There is no question that excessive moisture in the concrete can create serious problems when it begins to migrate out of the concrete after the coating is applied.

Coating application instructions often specify that the surface must be dry; sometimes they specify an allowable moisture content, expressed in a percentage. What they fail to mention is how deep this dryness must be or if there is a maximum vapor transmission rate allowable. There is an increasing awareness in the industry of these parameters. The flooring industry has shown a great deal of concern over vapor transmission, generally agreeing that 3 lbs/1,000 sq ft/24 hrs (1.4 kg/90 sq m/24 hrs) is an acceptable rate.

When Moisture Continues To Enter the Concrete from the Soil

Persistent and chronic moisture problems in existing floors are often the result of hydrostatic pressure or poor vapor barriers that allow moisture to migrate through the concrete. This situation presents 2 difficult problems. The first is how to determine whether there is in fact a continuing migration of moisture and, if so, the larger problem of dealing with it.

Cutting a core sample completely through the slab will indicate if there is a vapor barrier and if the soil is saturated or immersed. In a mature structure, a high reading or positive results from any of the tests mentioned above are good indications of a chronic moisture migration problem. Other good indicators of chronic moisture migration problems are ineffectiveness of continued drying processes and resaturation of the concrete after drying. Conditions inside the building must always be considered. A cold floor with a temperature below the dew point in the space will continue to take on moisture until it is saturated.

It is important to be aware of changing water tables. A slab that shows no sign of moisture migration can undergo total failure at any point during its service life as a result of rising water tables or saturated soil. Obviously, the first line of defense against vapor transmission from the soil is the placement of an effective and continuous vapor barrier under the slab. Although this is normally required and installed, too often, the plastic membrane used is inadvertently punctured during the pour. If the integrity of the vapor barrier is compromised, moisture migration into the slab can arise from heavy rains, higher than average seasonal rainfall, or altered drainage patterns.

Solutions for chronic moisture transmission are controversial and expensive, and they have limited success. The most effective method is always to remove the source of the water by improving drainage. In cases where the source cannot be eliminated, success becomes difficult to achieve. Some solutions for which success has been claimed include the following.

Penetrating Sealers

This approach uses fluid-applied primers or sealants that create a vapor barrier at the surface. The moisture is not permitted to escape. The challenge faced by the sealant is to withstand the force exerted by the moisture as it tries to leave the concrete. The adhesion strength should be as great as the tensile strength of the concrete, and the permeability must be low enough to stop the water from passing through the film. Some products, particularly in the flooring industry, are designed to allow limited amounts of vapor to pass through the surface, maintaining transmission levels below 3 lbs/1,000 sq ft/24 hrs (1.4 kg/90 sq m/24 hrs). Often, the hydrostatic pressure or vapor drive will exceed the strength or adhesion of sealer products, limiting their effectiveness.

Lateral Transfer Systems

One concept finding some application is installation of a system that allows the moisture to travel laterally between the concrete and the finish coating (or flooring) and escape at the perimeters. One method of achieving this involves applying a thick layer of water-permeable material on the concrete surface, and then applying the topcoats while leaving gaps at strategic locations to allow the moisture to escape the coating system. Another lateral transfer method utilizes a heavy, dimpled polyethylene sheet that holds the flooring system above the concrete, allowing the moisture to move laterally to a point where it can escape.

Breathable Coatings

On non-immersed surfaces when chemical or abrasion resistance is not a factor, breathable coatings can be a good option. Some coating products will allow moisture to pass through freely without affecting adhesion or long-term performance.

Removing Water from Concrete

When it has been determined that the source of the water is not continuous, the best solutions for achieving a coatable surface involve removing the moisture that exceeds allowable ranges. Moisture is removed most quickly with the right combination of air movement, temperature, and humidity.

Ventilation

It is important to ensure adequate air circulation in all drying applications. As moisture comes to the surface, air movement at the surface will carry it away and promote further evaporation.

Evaporation rates will triple with a 5 mph (8 kph) wind velocity and increase another 60 percent at 10 mph (16 kph). A 20 mph (32 kph) wind velocity at the surface of the drying concrete will promote evaporation at a rate 8.5 times that of a dead air space.[4]

Heating

Heat is another integral drying condition. Evaporation is accelerated as the air temperature increases in, as well as above, the concrete. Heat mobilizes the water in solid materials, allowing it to move to the surface and evaporate more readily.

Most often, forced air heating is used to heat the space above the concrete and, through convection, heat the concrete. Good air circulation will also aid in convection. A common mistake is to use direct-fired heaters to heat the space. Since moisture is a product of combustion, and a direct-fired heater introduces the combustion product into the heated air stream, the dew point temperature in the space is increased. This increase can be counter-productive, causing condensation on the concrete surface or the ceiling above.

Radiant heat can be useful to raise the temperature of the concrete in small applications. In Europe, small microwave heaters have also been used to spot dry concrete surfaces by warming the material.[5]

Dehumidification

For significant drying, the dew point temperature above the surface must be low enough for the water to migrate from the concrete into the drier air.

In many instances, displacing the moisture-laden air with drier, outside air will be very effective in lowering the dew point temperature. Colder climates offer an opportunity to utilize this option. In freezing temperatures, dew point temperatures are also very low. For example, if the outside air is 30 F (-1 C) dry bulb and 70 percent relative humidity, the dew point temperature is just above 22 F (-6 C). The cost of heating this air would have to be considered; however, heating could be useful in lowering the dew point in the space.

Bringing in outside air can be effective if one or more of the following conditions exist.

- The dew point temperature of the outside air is lower than the dew point temperature of the air in the building and lower than the temperature of the concrete.
- The outside dry bulb air temperature is below 40 F (4 C), and the outside air can be heated.
- A longer period of time is available for drying.

Using outside air to dry concrete becomes less effective when ambient dew point temperatures are very high (above 50 F [10 C]), if dry bulb temperatures are low and cannot be heated, or if air flow and air circulation are limited.

When ambient conditions are not present for the effective use of ventilation, the moisture in the space will have to be removed. Dehumidification equipment (Fig. 4) has been used to remove the moisture from the air space.[6]

Desiccant dehumidifiers will return air to the space at a very low dew point and a higher temperature. When combined with good air movement across the concrete surface, this equipment can provide the right combination of circulation, heat, and dry air needed for the fastest practical drying combination.

Through the process of drying the air above the concrete, the moisture is removed as a vapor, not a liquid. Therefore, this technique will be effective at any dry bulb temperature, achieving consistent results regardless of weather conditions.

This technology is used extensively and very effectively in the water damage restoration industry. Buildings of all types of construction are completely dried with desiccant dehumidifiers after they have been flooded. These machines will lower the dew point temperature in the building to a point where the moisture in the walls and insulation migrates readily to the surrounding air.

Combinations of desiccant dehumidification and cooling equipment are used to provide temperature control for occupied buildings during the drying process.

To summarize, the drying process in-

Fig. 2 - Moisture meter for the gel bridge test
Photo courtesy of Delmhorst Instrument Co.

Fig. 3 - Meter for radio frequency test
Photo courtesy of Tramex Moisture Detection Instruments, Black Hawk Sales, Inc.

Dehumidification equipment set up at Santa Theresa Water Treatment Plant, Santa Clara, CA
Photo courtesy of Munters Corporation, Moisture Control Services

cludes 4 major components, listed below in order of importance.
• Lower the dew point temperature of the air above the concrete.
• Promote rapid air movement across the surface.
• Raise the temperature of the concrete.
• Raise the temperature of the air around the concrete.

These components can be used alone or in combination; however, application of all 4 components will result in the fastest drying.

How Fast Can You Remove Moisture from Concrete?

The speed of the drying process is a function of many things, such as the following.
• Thickness of the concrete: Thicker slabs dry more slowly.
• Concrete density: Dense concrete will dry more slowly.
• Moisture content: More water content requires more time to dry.
• Temperatures of the concrete and the air above it: Heat energizes water molecules.
• Dew point temperature of the air above the concrete: Low dew points will encourage migration of water from the concrete.

The rates of extraction will vary as the concrete dries and moisture becomes less available. A monograph published by the American Concrete Institute shows a rough approximation of the relationships of the different conditions and their impact on the drying rates of concrete.[4]

Summary

Moisture continues to create application and performance difficulties for concrete coatings, and successful concrete applications rely on an acceptable level of residual moisture. Several methods are available to measure moisture content, with a wide range of prices, speeds, and qualitative results. A combination of 2 or more methods makes possible accurate, documentable results along with spot readings for speed and confirmation of readings. Concrete dries most quickly when the dew point temperature is low, the concrete is warm, and the wind velocity is high. Dehumidification has proven to be useful in promoting accelerated drying on projects requiring high-performance coatings for concrete. ❑

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