TECHNICAL PAPER – TP 007
ALKALINITY AND MOISTURE IN CONCRETE SUBFLOORS

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INTRODUCTION

With the introduction of the new standard for installation of resilient floor coverings AS1884-2012, a number of problems have been highlighted which require a more detailed consideration. This paper deals with two issues that are not really that well understood, floor moisture and also slab alkalinity. They have become important because of the requirement to accurately measure the moisture content in concrete, and also the new requirement to determine the pH level (alkalinity/acidity) of the slab before laying flooring systems.

WHY ARE THESE TWO MEASURES IMPORTANT?

Moisture

In the case of moisture, this is a reference to water that is present in the concrete, which is a problem because excess moisture leads to damage to the flooring adhesive, damage to the floor covering, de-bonding of the floor covering, decomposition of any underlayments and development of smell, mildew and mould. The purpose of measuring the moisture is to determine whether or not it exceeds a level that will cause problems for the flooring materials.

The revised Standard requires that the measured moisture content not exceed 75% Relative Humidity when measured at a standard nominated depth in the slab, or 70% Relative Humidity when measured on the surface.

pH

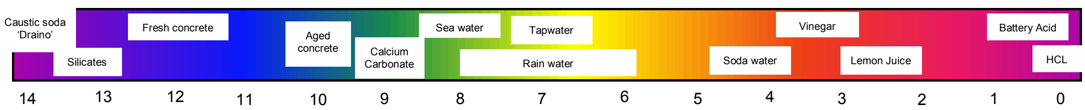
The pH is a measure of the degrees of alkalinity or acidity in a subfloor, which is either a result of the concrete chemistry or surface treatments. Where the pH is high, the state is called alkaline which can result in the break down of the flooring adhesive and in some cases the floor covering itself. The opposite situation is low pH which is unlikely to occur as it will result in decomposition of the concrete itself, little-alone anything that is placed on to it.

The standard recommends the pH not exceed 10, which is also the case for AS/NZS2455 which is the textile floor covering standard.

Therefore, these two properties of the concrete can have a crucial effect on the performance of a flooring system.

PH IN MORE DETAIL

The term pH is a physical chemistry name for the scaling used to describe the concentration of acidity or alkalinity in a solution. For practical everyday purposes it has been divided into a logarithmic scale ranging from 0-14; where pH 0 = highly acid, pH 14 = highly alkaline, and pH 7 = neutral (tap water). The schematic below gives common materials and their pH.



The actual workings of pH are defined as the concentration of acid species H^+ and alkaline species OH^-. The most basic is actually simple tap water where the equilibrium that occurs is

$$H_2O \leftrightarrow H^+ + OH^-$$

For our purposes though, the measurement of pH occurs where some sort of chemical species is dissolved in WATER SOLUTION, and it is actually defined as

Numerically pH + pOH = 14

$-\log_{10}[H+]$ of acidic solutions and (pH range 0-7)

$-\log_{10}[OH-]$ for alkaline solutions (pOH range 7-14)

where the –ve log of the molar concentrations of the material dissolved is being considered.

We will be dealing mainly with alkalinity because acidity is a rare situation and leads to far more serious consequences than the floor covering failing. The source of the alkalinity comes from two potential mechanisms.

1. The first source is from the cement in the concrete. Cement when manufactured contains free lime ($CaOH_2$) and also creates more 'lime' when it reacts with water during hydrolysis of the Calcium-Alumino-Silicates that make up the cement. Free lime is partially soluble in water (~2gms/litre) and the pH of a saturated lime solution is 12.4 ($CaOH_2 \rightarrow Ca^{2+} + 2OH^-$). The wet concrete therefore contains a saturated solution of lime in water which generates a relatively high pH. As the concrete dries and cures, the free lime present is converted to $CaCO_3$ (limestone) by the action of Carbon Dioxide in the air (when Carbon Dioxide dissolves in water it actually creates a weak acid called Carbonic Acid, i.e. Soda Water). This reaction is a gradual process and results in the pH value falling over time. The pH of Calcium Carbonate in water is 9.4 and very low in solubility (0.015gms/litre), hence old concrete has much lower pH. Another peculiar property of a saturated lime solution is that the pH can actually be higher in cold conditions because the lime is more soluble in cold water.
2. The second source of raised pH is a result of treating the concrete with reactive silicate type 'waterproofing' materials. The reactive material in these preparations is a hydrated silicate or derived silica sol, based on Sodium, Potassium or Lithium Silicate. These chemicals are alkaline in their own right and are highly soluble; the pH of a Sodium Silicate solution exceeds 12.6, however these materials are stabilised by the addition of a stronger alkali such as Potassium or Sodium Hydroxide (KOH or NaOH). These are strongly alkaline such even a solution of around 0.5gm/litre has a pH of 12. The concentrations of a stabilised silicate is higher, and a pH exceeding 13 is normal. If the pH falls the silicate destabilises and polymerises. The treated surface, retains the raised pH for a period of time, but eventually also carbonates and the pH falls. The time is dependent on the presence of moisture and levels of Carbon Dioxide.

The point to note here is that the measurement of pH requires water to be present, because pH is a measure of the concentration of the species in water. The implication is that you can have a material that contains alkaline species, but nothing will happen until water is added and it is made soluble. Conversely, you can have old wet concrete, that no longer contains alkaline materials so shows a low pH. The rules of thumb therefore are

a) Concrete can be damp, but not necessarily have a high pH if it is older and the lime gone
b) Concrete can be dry but have a high potential pH when wetted because it contains lime or has been treated in the past
c) Young (Green) and usually damp concrete will almost certainly display a high pH, as will freshly treated concrete.

Elimination of High pH in Concrete

The presence of raised pH creates problems for the adhesives because the alkalinity causes the ester bonds in the adhesive rosin or acrylic base ester chemicals to break (called alkali hydrolysis or saponification). It also can attack the backings of some types of floor covering, and can even if high enough affect some types of applied coatings such as water based epoxies.

The elimination of raised pH requires the surface to be neutralised which is an undesirable activity as it requires the handling and applying acidic materials. It results in the floor being made wet again, and also can create issues with disposal of nominally contaminated waste water.

The most commonly used acids are diluted Hydrochloric Acid (formula HCl, aka Muriatic Acid or Spirits of Salt, supplied as 33 or 37%) or Phosphoric Acid (formula H_3PO_4, supplied as 85%). In the case of HCl, even a dilution of 1 part in 100 has a pH of 1 which is highly acid.

It is feasible to use Acetic Acid except for the strong smell ((Glacial Acetic Acid is 100%, but low concentrations, ~5%, are present in vinegar with a pH around ~3.5). In North America some flooring installers actually use Soda Water which they make by bubbling Carbon Dioxide (Beer gas) into water which has a pH of ~4.

We do not recommend the use of Hydrochloric Acid because it is highly corrosive, can be dangerous to mix and handle and creates acid fumes which attack metal fixtures. Glacial Acetic Acid is also problematic as it has a strong and irritating odour. The use of Sulphuric Acid is not recommended at all, partly because of its dangerous properties, but also because it creates insoluble sulphates when it reacts with the cementitious materials.

When the concrete pH is less than about 11.5, it can be coated with the water based epoxy Ardex WPM300 which will suppress the moisture, but also isolate the concrete surface.

Measuring pH

There are two basic methods for measuring pH of materials. One is to use an electronic meter and the other is to use a colour changing chemical.

In the case of most meters, this is really a laboratory technique and the powdered material is placed into distilled water and the pH of the resultant solution measured. The material needs to be added accurately so that a consistent method is used to obtained readings, and the instrument needs to be calibrated. There are also small hand held units that work in a similar way and can be used on site. In both cases, calibration is performed at the time of use with prepared buffer solutions of known pH.

Colour change chemicals can be in the form of pH papers, dyes, colour change pencils or other materials, but the basic mode of operation is the same. The indicator chemicals change their colours according to the pH of the liquid they come into contact with.

The most common method is lightly scrape the surface of the concrete and then wet it with distilled water. The indicator paper is then placed into the water and the colour change gives a pH reading. The more accurate papers use several different panels with different indicators. An important factor is that colour blind people may have trouble with these indicators, and the test does require good light to read the strips correctly.

Liquid chemicals are used in 'soil test kits' and these can also be used where there is sufficient powdered substrate material to work with.

MOISTURE IN MORE DETAIL

Moisture in concrete can be there because the concrete is young, and it still contains water from the original installation, or it can be subject to moisture ingress from the outside environment. In this discussion we are not going to delve into sources of moisture, but concern ourselves with the measurement of it.

There are two sorts of moisture to think about, liquid moisture we simply call water, and water vapour. Liquid water can be stopped by a moisture barrier system, however water vapour is much more difficult to deal with, and the moisture barriers suppress it, but do not fully prevent it from passing. When conducting moisture measurements, the majority of test methods are in fact measuring the water vapour, rather than liquid water.

What can happen with concrete is that in its lower depths (measured from the slab top) the matrix pores can be full of liquid water, whilst the upper levels can contain moisture vapour, with an equilibrium between the two. The surface of the concrete can in fact be relatively dry, as water evaporates off into the atmosphere, but lower down remains wet. Green concrete will progressively dry through loss of water in this way, but concrete subject to rising damp can remain in this pseudo-wet state indefinitely.

Electrical methods—Percent Moisture Contents (% MC)

With this type of test, the probe is either directly measuring resistance or conductivity, or indirectly measuring capacitance (a complex form of resistance using impedance). These methodologies appear to have been handed down from the timber industry where probes are used to measure timber moisture content.

Resistance and conductivity are inverse measurements, that is when resistance is low conductivity is high and visa-versa. In fact conductivity and resistance are related in this way,

$$Resistance = \frac{1}{Conductivity}$$

Resistance is measured in ohms, whilst conductivity is measured in mhos, but **meters are calibrated in percent moisture** usually. This number is intended to be exactly what it appears to be, a measure of the actual physical weight of water in the concrete.

> Note: The older version of AS1884-1985 set this value at less than 5.5% moisture content. This can be measured accurately by comparing the 'wet' and oven dry weight of a sample of the floor concrete, a process that is not really workable in a construction environment.

Pure water is non-conductive, but water in concrete contains dissolved salts and this is what makes the water conductive and allows for measurements to be made. When the probes from the electrical type meters contact the surface, a small current is passed into the concrete, the meter then measures how easily it travels from one probe to the other. This current movement is facilitated by water in the concrete pores, the easier it passes, the higher the conductivity and hence the higher the moisture reading (resistance works in the opposite way).

The major issues with these methods are that they do not penetrate far into the surface, they can be fooled by the presence of conductive materials (such as re-bar) and also effected by concrete density and additives. That being said, this method has been in use for many years and when used judiciously has been successful for most jobs.

Humidity methods - Relative Humidity (%RH)

There are a wide range of methods for measuring moisture via humidity, but it is important to recognise that humidity is a more complex concept than straight moisture content. There are several terms that are covered by humidity, some of which are confusing;

> *"There are three main measurements of humidity: absolute, relative and specific:*
>
> *-Absolute humidity is the water content of air.*
>
> *-Relative humidity, expressed as a percent, measures the current absolute humidity relative to the maximum for that temperature.*
>
> *-Specific humidity is a ratio of the water vapor content of the mixture to the total air content on a mass basis."* (http://en.wikipedia.org/wiki/Humidity)

We are primarily concerned with Relative Humidity which is what is measured, but it is important to understand the first two as they give background to the testing process.

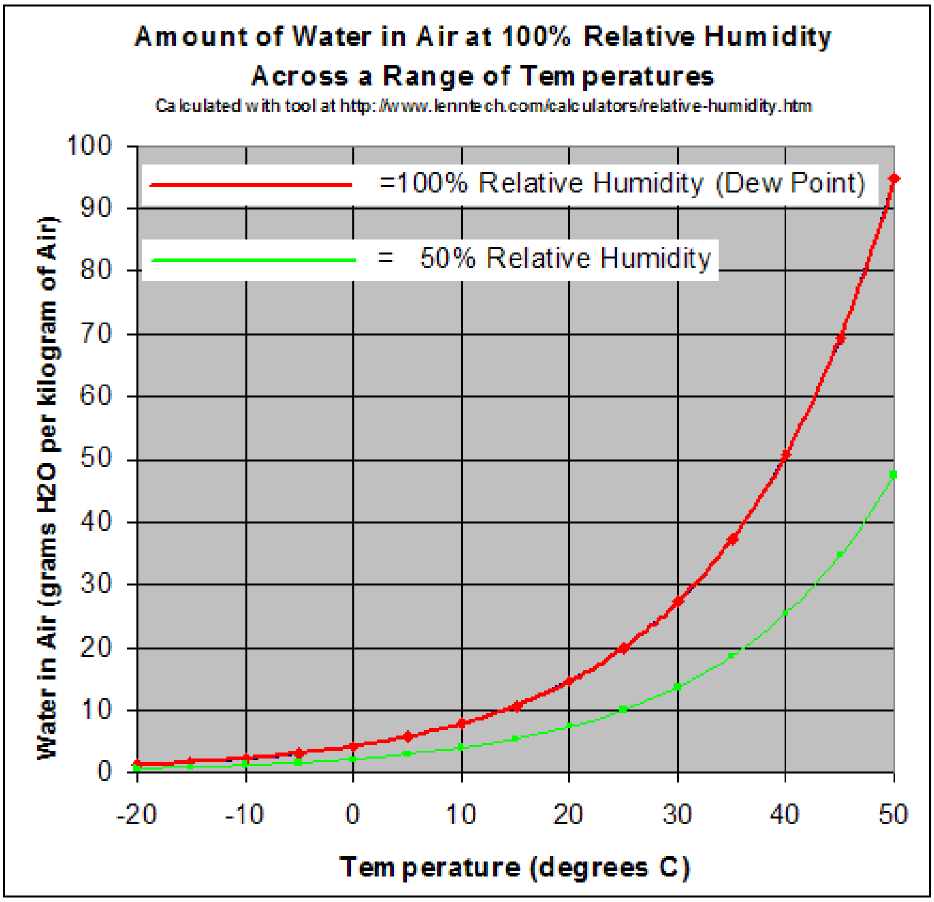
Absolute humidity is the amount of water vapour (mass) per unit volume of air. It ranges from nothing to about 30gms/m^3 ,but changes with temperature or pressure alter this value. This measure is used for chemical and physical engineering purposes, and is something that relates to the operation of air-conditioning (HVAC). When the absolute humidity is reduced by the operation of HVAC, it causes the equilibrium of moisture at the floor-air interface to change, and promotes the movement of water from lower down in the concrete to the surface. In effect it reduces the water vapour partial pressure and then promotes the movement of moisture to the surface to re-establish the equilibrium.

Relative humidity (usually abbreviated as %RH) is the ratio of the partial pressure of water vapour in the gas-water mixture, to the saturated vapour pressure of water at those conditions. This is effected by the actual water content and temperature. (Partial pressure is the pressure exerted by the water vapour as gas, if it alone occupied that volume of gas at the same temperature—remember air is a mixture of gases, but it can be measured notionally in air-less mixtures).

The measure of relative humidity is a percentage, where the water vapour partial pressure is divided by the saturated water vapour pressure at a fixed temperature x 100. This value is important because it indicates the likelihood of water precipitating. At low temperatures the air can carry less water so it is more likely to precipitate from the gas phase and become liquid when moist air is cooled, and high humidity can also have the effect of making drying by evaporation less effective at higher temperatures. There are some rules of thumb for %RH that can be observed; for example where the RH% is 100, it will be raining because when it reaches this figure it is the Dew Point, and theoretically values can go as high as 200%, which is under water. When the % RH rises above about 85% the chance of liquid water being present in a building system at "normal atmospheric temperatures" is high (it is liquid water that is actually the problem with floor coverings, not the vapour per se).

The graph on the next page (http://en.wikipedia.org/wiki/Relative_humidity) gives the relationship between relative humidity, dew point and temperatures, showing the conditions that will result in the development of water condensation.

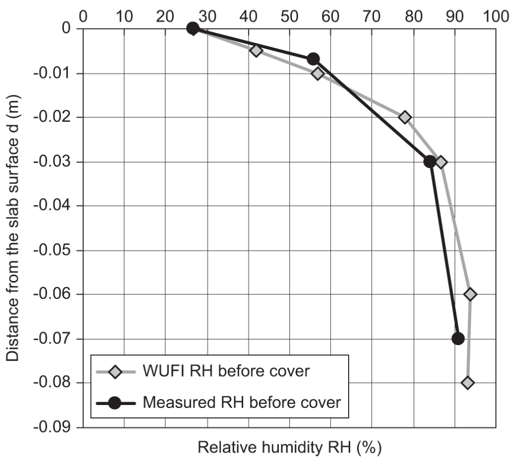
What we are measuring as moisture in the floor situation then, is the amount of water vapour present in the concrete matrix, or just above it, compared to the amount which could be there for that amount of air. The point being that once a threshold value is reached,

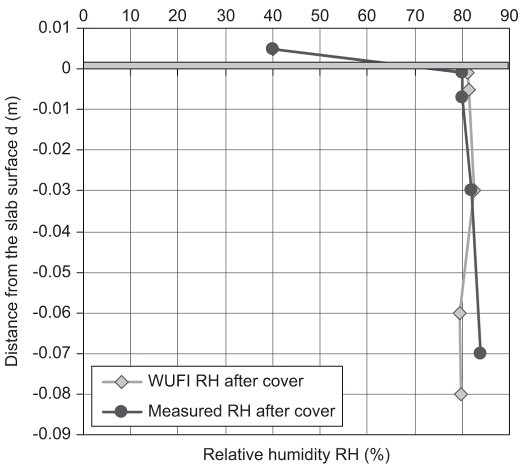


the risk of water condensing under a floor covering is significantly increased.

Measuring the % RH on a floor

The 'traditional' method of measuring the moisture content was to place a sealed box on the floor with the hygrometer inside the box. The moisture then rises from the subfloor into the box and comes to equilibrium inside the box and this is reading. This value was fixed at 70% RH in the original AS1884-1985 and also BS8203. Research done in the last 10 years has suggested that this figure is too high because the data and anecdotal field evidence had shown that whilst the floor surface was dry because of evaporation, lower down the concrete remained 'wet' (see Rantala & Leivo 2009). The two graphs below





come from that reference (Figs 6 and 7 p336). The left figure shows the measured moisture content with depth for a test slab before being covered, and right after the placement of floor coverings. As can be seen, the deeper concrete remained wet, but when the floor covering was placed the moisture then rose to the surface under the covering. This type of research led to the proposal for an in-slab moisture test where the deeper areas were investigated. The methodology developed provided for a humidity test at a nominal 0.4x times the slab thickness; for a 150mm thick slab on ground this translates to 60mm down a hole drilled into the slab. The probe remains in place and the humidity level is allowed to stabilised and is then measured. The process is detailed in ASTM F2170 which is the reference test method in the revised AS1884-2012. The new recommended test value was specified as 75% RH at this depth, results in a much lower surface level than the 70% figure used before. Since this method requires a hole drilled into the slab, it is invasive, but the process of drilling also locally dries the concrete by frictional heat, so the test probes must be left in place for the specified times to equilibrate. However, it is also clear that if the measured value very quickly rises above the cut off figure, then the eventual result will be a high reading.

What is the correlation between % RH and % MC?

A question that is often asked what is the correlation between these two measures? The short answer is that there is no direct correlation; that is, under the old system 5.5% MC was not equal to 70% RH. The former 5.5% MC figure is really about 85% RH and the latter 70% RH figure around 3% MC. With the 75% RH at depth, this equals around 60-65% RH at the surface and about 2.5% MC. Therefore, the methods used produce different results, and it is pretty clear that under the old standard, materials had to be more tolerant of moisture than under the new. Ironically though, the manufacturers of the flooring materials are now actually rating their products to perform at higher moisture levels. Partly this is an improvement in technology, but also a recognition that the factor of safety in these materials is more than appreciated. However, it needs to be recognised that the new test method is more a more accurate appraisal of the state of the concrete moisture, and also likely to be more precise because tests are done at a standard hole depth, rather on an irregular surface.

Why has a version of the 70% RH method been retained in the new standard?

The non-invasive version of the humidity test (ASTM F2420) was retained because in some situations it is not feasible to drill holes in the slab. In these cases the surface test is the second choice method, and whilst it does not result in a pass figure for as a dry a floor as the 75% at depth measure, it is still a relatively dry concrete.

SUMMARY

The new flooring standard has changed some of the required properties of the concrete before a floor covering is laid. These measurements are more technical than the older processes. It is important to recognise that when instrumentation is used, the equipment must be calibrated, test records kept, constant methodologies used, and the test and its results properly understood with the correct interpretations. Installers need to decide if they are correctly set up and inclined to do testing this way, or pass the process to a testing professional.

Reference

Rantala J & Leivo V. (2009) Drying of in situ cast concrete ground slabs and covering criteria. *Building & Environment 44*, pp 331-337.

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