Methods for measuring relative humidity (RH) in concrete floors - development and uncertainties

Nilsson, Lars-Olof; Åhs, Magnus

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Methods for measuring relative humidity (RH) in concrete floors – development and uncertainties

Lars-Olof Nilsson[1], Magnus Åhs[1]
[1] Laboratory of Building Materials, Lund University, Sweden

ABSTRACT. An RH method was proposed in the late 1970s to replace the traditional CM-method in Sweden and from 1984 the RH-method is the dominating method to measure moisture in concrete floors before applying a moisture sensitive floor covering. The required total uncertainty must be smaller than 2-3 % RH depending on the method used. The paper describes the historical development of RH measurements in concrete materials and structures as such and the development in Sweden for concrete floors during some 30 years. A number of decisive parameters are discussed and quantified such as sampling techniques, sample size, sample properties, moisture capacity of sensors and probes, calibration, drift of sensors and various temperature effects.

Keywords: relative humidity, concrete floors, samples, holes

1 Introduction

The Laboratory of Building Materials at Lund University in Sweden has been measuring RH in concrete floors since the mid-1960s. An RH method was proposed in the late 1970s to replace the traditional CM-method and from 1984 the RH-method is the dominating method to measure moisture in concrete floors before applying a moisture sensitive floor covering. The required total uncertainty must be smaller than 2-3 % RH depending on the method used. The methods being developed in Sweden are now adopted by the other Scandinavian countries and are considered for applications in the USA.

The paper describes the historical development of RH measurements in concrete materials and structures as such and the development in Sweden for concrete floors during some 30 years. The two dominating methods, measuring on samples and measuring in holes on site, are described in detail and the decisive parameters are quantified.

The parameters dealt with are mainly sampling techniques, sample size, sample properties, moisture capacity of sensors and probes, calibration, drift of sensors, various temperature effects (temperature differences, temperature level, temperature variation), positioning and orientation of sensors etc.

2 History of development

There is a need for measuring moisture in concrete floors before applying a moisture sensitive floor covering, such as PVC-sheets, ceramic tiles, linoleum flooring, wooden tiles, etc. [1][2][3]. Traditionally, these moisture measurements were done with the CM-equipment, the calcium-carbide method, as still is done in i.e. Germany and Austria. The CM-method measures the moisture content of a small sample. This method was criticized [1] for several reasons:

- The moisture content of the substrate concrete says nothing about the moisture conditions in a floor covering; RH would be a much better measure since RH will be equal in the contact point between two different materials,

- The moisture content is very difficult to translate into an RH, with accuracy; the concrete composition and the moisture history must be known in detail,

- The moisture content of a small sample of concrete cannot be representative for the moisture content of a heterogeneous material like concrete with large aggregate; RH is correct in any such sample.

Consequently, a method was needed to be able to measure RH in concrete floors, in situ. A first proposal was made in 1970 to use a "cup method" where the concrete surface is sealed and a cup, with an RH-probe, is placed in the middle of the sealed area. The method is similar to the one used today in UK. The method was not accepted, mainly because the required time to reach equilibrium under the seal is too long, possibly several months.

Two other methods were proposed by Nilsson [1]: measuring RH on a sample taken from a certain depth in the concrete floor or measuring RH in a hole at that depth. A suitable depth was theoretically estimated by computer calculations in 1979 [1] to 0.4•L in a homogenous floor slab with a thickness of L and drying one-way.

Suitable equipment for these measurements was not available in the 1970s [4][5]. A global search was made and small, capacitive sensors from Vaisala OY in Finland were selected for producing RH-probes that could be used for the two methods [1]. Eventually, Vaisala and other companies started to produce RH-probes themselves that were robust enough to be used on a building site.

With these probes the two methods could be applied in the construction industry and these methods finally replaced the CM-method in 1984 and were widely used.

The accuracy and uncertainty when making measurements were, however, not under control. A thorough work was initiated that resulted in strict descriptions and control of how the measurements should be performed and the uncertainties were quantified. Today, a large number of "authorized moisture controllers" [6] are used by industry to make accurate measurements with uncertainties not larger than 2 or 3 % RH, depending on the method used.

2 Measuring RH on a small sample

The main method for accurate measurements of RH is the method of measuring on small samples extracted from a certain depth. The method is shown in figure 1 [2]. The sample is stored in a glass test tube with a rubber stopper. Since no moisture leaks out at all the RH measurement can be made at any future occasion. The measurement starts with removing the rubber stopper and replacing it with an RH-probe. The reading is taken after moisture equilibrium has been reached in the system of sample - enclosed air volume - probe filter - RH-sensor. This may take one or two days, depending on the denseness of the concrete sample. The procedure is done under temperature-controlled conditions.

During the time required for reaching moisture equilibrium a small amount of moisture is being transported from the sample to the initially dry air volume, filter and sensor. Consequently, the moisture content of the sample is somewhat lower when the reading is taken than the initial moisture content of the sample. For obtaining acceptable results this systematic error must be small, which is obtained by using an RH-probe with a small moisture capacity, i.e. an RH-probe that needs only a very small amount of moisture to change its reading. The error may be quantified by calculating the amount of moisture being exchanged, assuming that the probe, sensor and air volume has an initial RH corresponding to the surrounding air. This is then translated to an RH-drop that is a consequence of the drop in moisture content of the sample [2]. The calculation can be done by equation (1), knowing the moisture capacity of the probe in the RH-interval. The equation is quantified in figure 2.

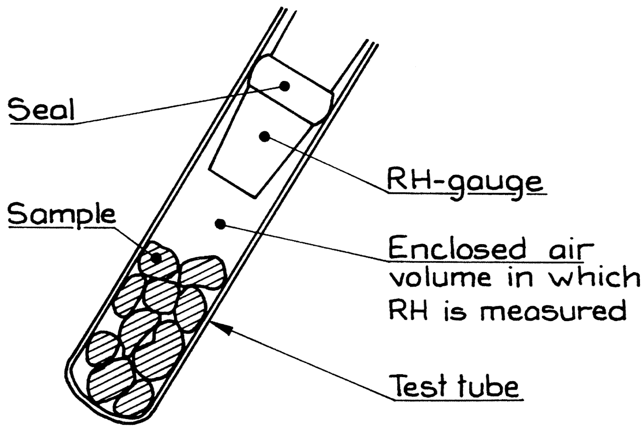

Fig. 1: Method of measuring RH of a sample [2]

The RH-drop of the sample due to moisture being exchanged to the enclosed air volume and the probe is given by

$$\Delta RH = \frac{m_w\left(RH_0, RH\right) + v_s(T)\cdot\left(RH - RH_0\right)\cdot V_{air}}{V_{sample}\cdot K(RH)} \qquad (1)$$

where $m_w(RH_0, RH)$ is the moisture capacity [kg] of the RH-probe between the initial humidity RH_0 and RH; v_s is the vapour content [kg/m^3] at saturation at the current temperature T; V_{air} is the volume [m^3] of the entrapped air; V_{sample} is the volume [m^3] of the sample; K is the moisture capacity [kg/m^3] of the sample material at the humidity level RH.

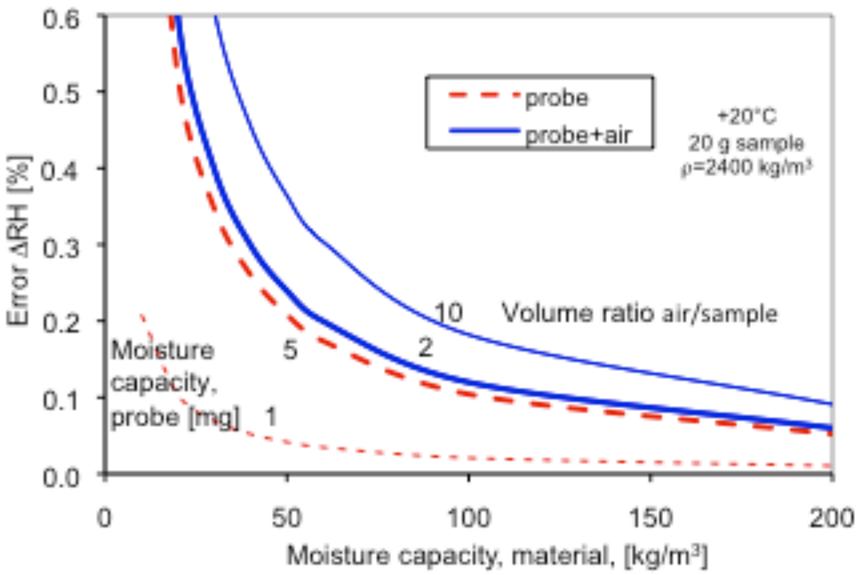

Fig. 2: Systematic error when measuring RH on a small sample

The moisture capacity K of the sample material is the slope of the desorption isotherm at the initial RH. For traditional concrete K is some 100-200 kg/m^3. Compared to this value the "moisture capacity" of the enclosed air volume, the vapour content at saturation (17.3 g/m^3 at +20°C) is insignificant. The decisive moisture capacity is instead the moisture capacity of the RH-probe. The RH-probe must be selected based on information on this property.

The systematic error is quantified in figure 2 for different sample materials, two different moisture capacities of the probes and two different volume ratios between the volume of the sample and the volume of the enclosed air volume. As seen, with RH-probes with these properties the systematic error can be limited to some 0.1-0.2 % RH for traditional concrete. Some high-performance concretes, frequently used in Sweden as "self-desiccating concrete" for floors, have a much flatter desorption isotherm around 85-90 % RH and, consequently, a much lower moisture capacity. The systematic error for such a concrete may be up to 0.6 % RH, which has to be corrected for [2][6].

3 Sampling technique

The sample from a concrete floor must be taken in such a way that significant drying of the sample does not occur. The sample must be taken from an exact depth. Several techniques have been used but today the sampling technique is standardized [6], cf. figure 3.

Prior to extracting a sample the surface temperature is determined by using an infrared temperature sensor. This reading may serve as a comparison to the surface temperature determined at the sampling depth. When drilling in a high strength concrete the friction from drilling may increase the temperature, hence possibly drying the concrete.

A core drill with a periphery diameter of minimum 90 mm is used to successively drill into the concrete slab in segments, maximum 30 mm at the time. This procedure limits the temperature increase caused by the heat generated from the core drill. The core drill is used without water as lubrication in order to prevent an increase of moisture content.

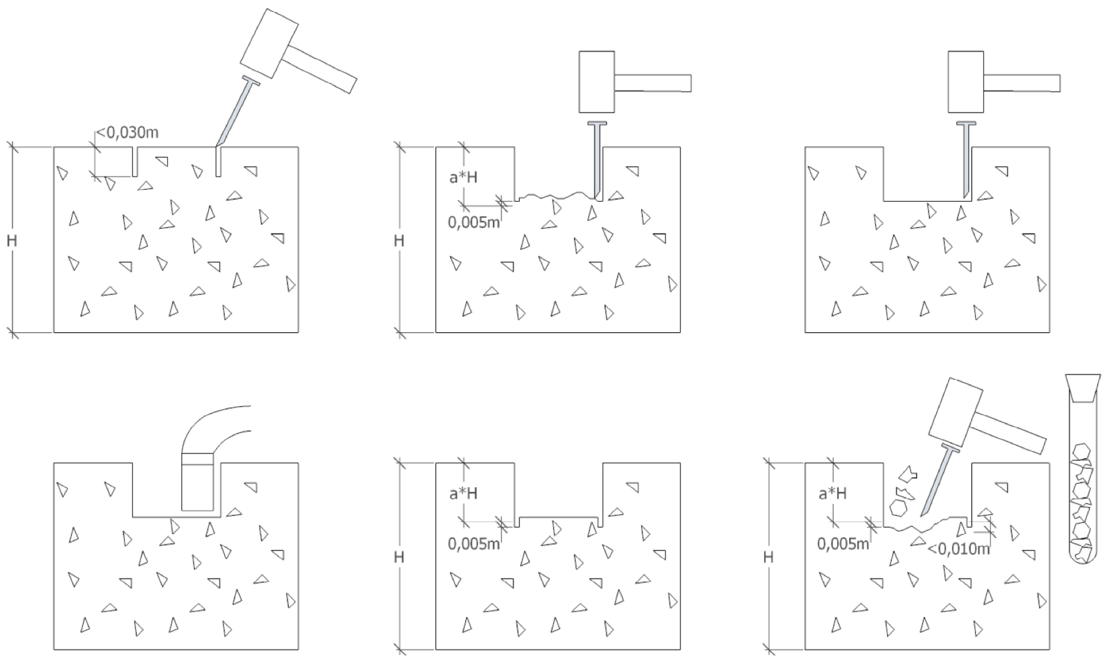

Fig. 3: Procedure of extracting a sample from a concrete floor slab

As the drilling of the segment is completed, the concrete core is chiselled off to achieve a horizontal floor at the bottom of the hole. Before continuing drilling the next segment all loose material is to be removed by a vacuum cleaner. This prevents concrete from a shallower depth to be unintentionally added to the concrete from the desired depth. Such an addition would affect the RH reading.

Drilling continues until reaching a depth of 5 mm above the desired sampling depth. At this depth the core is chiselled off to obtain a horizontal surface. This surface becomes the head of the core from which the sample material is extracted. The surface is carefully vacuum cleaned to remove all dust and loose concrete particles from the drilling procedure. Drilling is continued until achieving a depth of 5 mm below the desired depth. Then the surface is vacuum cleaned once again to remove dust from the drilling.

Thereafter sampling begins by extracting minimum 5 mm concrete pieces by chiselling. Pieces containing a large degree of cement paste are selected, as these contain the highest degree of moisture. They are to be put inside a glass tube and sealed with a rubber stopper immediately after extraction, hence reducing exposure to dry or humid environment at site. Pieces containing concrete at >10 mm below the desired depth are not to be used, thus avoiding parts considered too humid. Concrete pieces exposed to air exceeding 30 seconds are not to be used. In order to obtain a representative RH reading the glass tube must contain minimum 15 cm^3 of concrete pieces.

During sample transport and storing at the laboratory the temperature has to be logged. If the glass tube is subjected to a low temperature there is a risk of achieving air moisture condensation on the glass, which would affect the RH reading.

This method may be used when the surrounding environment does not provide a stable temperature or at sites where an RH sensor may be damaged if left unattended. In addition it is also suitable for determination of the RH distribution through a concrete slab.

4 Method for in situ measurements

RH measurements in concrete slabs may be performed at site, in situ, by exposing an RH sensor above a concrete surface and seal off the surrounding air. By drilling a hole into the concrete it is possible to determine the RH at the desired depth. The hole depth is determined by using a vernier calliper from the concrete surface to the hole floor circumference. In case the hole depth exceeds 2 mm below the desired depth another hole has to be drilled. In that case a second hole may be located at least twice the desired depth from the first hole to avoid possible disturbances from it.

A bottle brush with a suitable diameter is used to remove dust from the hole circumference. Subsequently the hole is vacuum cleaned by using a small hose, which may reach the hole floor or use an air blower with a similar hose.

Subsequently a plastic tube is inserted inside the hole. Sealing paste is placed under the plastic tube circumference and between the plastic tube and the hole top in order to seal off air from concrete above the desired depth.

After sealing an insertion of the plastic tube the hole may have been polluted with dust from the drilling. That dust is removed by using the vacuum cleaner or air blower once again. The air tightness is afterwards verified by inserting the spout of a compressed, rather stiff, rubber bladder into the plastic tube. The rubber bladder is not to expand by its own if the installation is to be considered airtight [6].

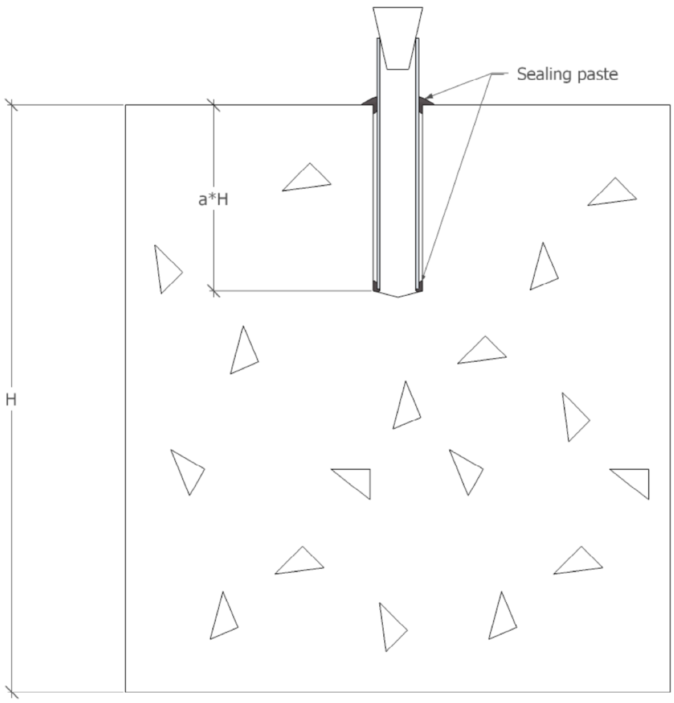

Fig. 4: A hole in a concrete slab with an inserted plastic tube. Sealing paste prevents possible moisture transport along the plastic tube.

The drilling procedure generates heat, which may dry the concrete to some extent. This drying is rather limited and the humidity of the surrounding material will in time redistribute and thereby moisturise the concrete. The temperature increase of the surrounding material also affects the air temperature, which in turn increases the dew point. Both the drying of the material and the temperature increase results in an apparently low RH reading. Therefore it is important to wait for at least 48 hours before an RH reading may take place [1][7].

In addition to heat of drilling environmental temperature fluctuations affect RH readings [1][8]. This was shown by Åhs [9]. Therefore the sensitivity of the RH sensor to fluctuations in temperature and humidity may result in an inaccurate RH reading. By insulating the concrete slab surface surrounding the hole it is possible to reduce such fluctuations [9], hence stabilizing the RH reading.

5 Applications in screeded concrete floor slabs

In recent years, floor slabs are commonly screeded with a layer of mortar or self-levelling compound to form a smooth base for flooring. This type of construction requires special attention to the moisture redistribution when estimating the future maximum RH beneath the flooring. Therefore a method was developed by Åhs [10], which makes it possible to estimate the maximum achieved RH in a two-layer slab.

In figure 5, there is a presentation of three important phases in the production of a screeded concrete slab, which have an impact on the moisture distribution. The cross section of a screeded slab is shown at the top and the bottom part shows the desorption isotherm and the scanning curves, which are giving the equilibrium conditions during rewetting and reaching equilibrium at different depths.

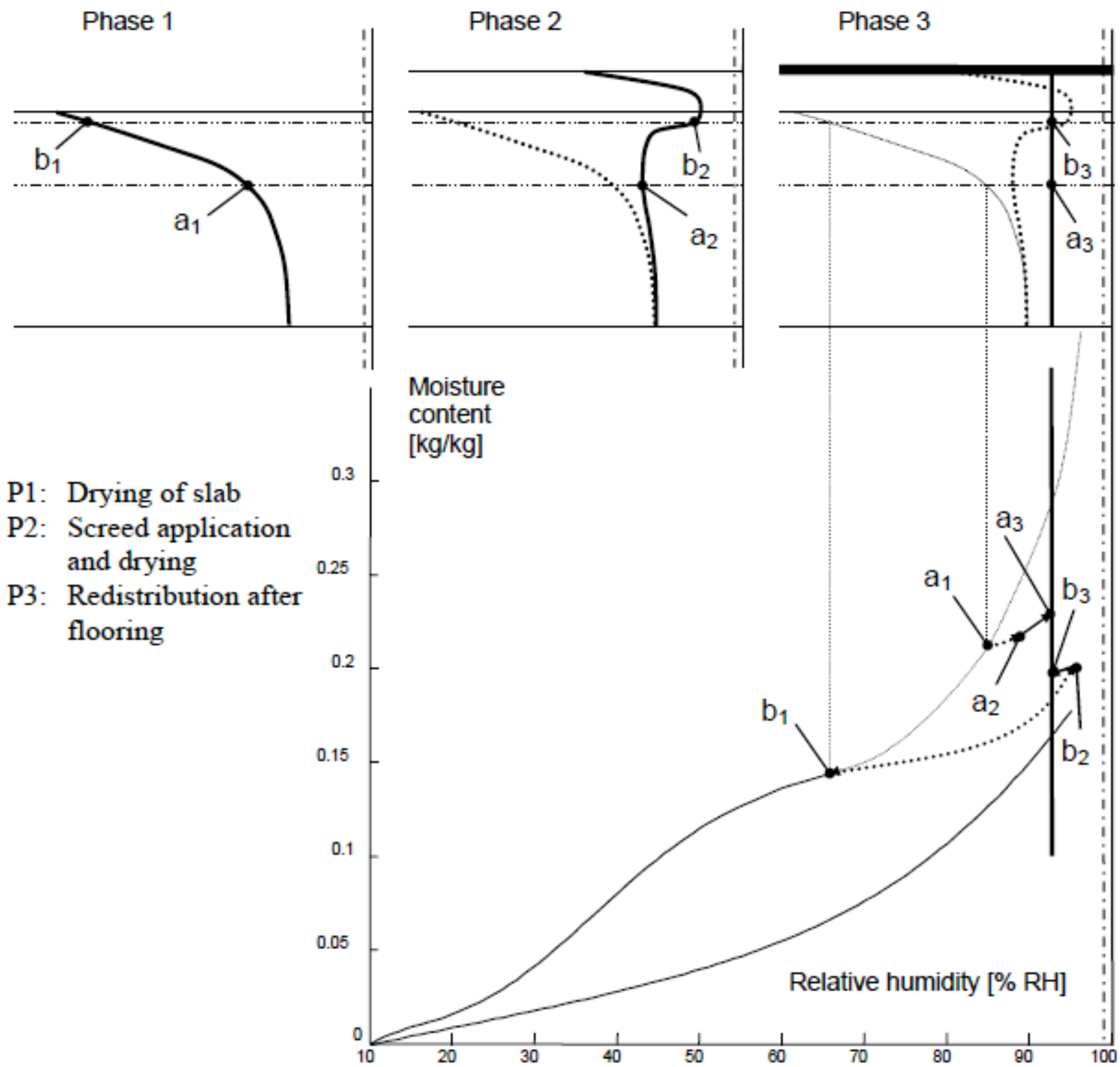

Fig. 5: Redistribution of moisture during three phases in a screeded concrete floor [10]

In the first stage the slab dries which is shown as a curved line, representing the moisture distribution. All points are following the desorption isotherm. The dry surface will then become humidified when the wet screed is applied and the top part of the concrete slab will follow scanning curves. After a more or less impermeable flooring material is applied on top of the screed moisture equilibrium is eventually reached, shown by a vertical line in figure 5. During this process points at different depths are following different scanning curves. To be able to evaluate the future maximum RH underneath the flooring material RH must be measured at several depths and the measured RH-profile must be evaluated by utilizing the scanning sorption curves. This procedure is well described by Åhs [10].

7 Conclusions

The technique to measure RH on small samples extracted from suitable positions in concrete floors containing excess moisture has been found to be very reliable. The systematic error due to moisture required by the RH-probe, -sensor and enclosed air volume is insignificantly low for traditional concrete but for high-performance concrete a correction by some 0.5-0.6 % RH must be made. A total uncertainty of less than 2 % RH can be reached, with a careful sampling technique and controlled temperature conditions.

When measuring RH in a drilled hole on site, the hole must be sealed with a tube, only leaving the bottom of the hole open for measurement. The hole must then cool of a couple of days after being heated during drilling. Temperature variations must be under control when the reading is taken.

Screeded concrete floors require the RH-profile to be measured. The results must then be evaluated by using the scanning sorption isotherms to find the future maximum RH underneath the flooring materials. For accurate results in homogenous floors measurements must also be evaluated in the same way, by considering the scanning curves to find a suitable depth for sampling of measuring in a drilled hole at one depth.

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Contact point: Prof. Lars-Olof Nilsson, Laboratory of Building Materials at the University of Lund; P O Box 188; SE-221 00 Lund; Sweden. Phone: + 46-46 222 7408; Fax: + 46-47 222 4427; E-mail: lars-olof.nilsson@byggtek.lth.se