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INFLUENCE OF MOISTURE CONTENT ON WATER ABSORPTION IN CONCRETE

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Abstract: Concrete durability is evaluated by a number of properties - such as water absorption and chloride diffusion. Each of these properties can be measured using standardized methods. Water absorption can be linked to porosity and therefore to eventual deterioration. Tests based on absorption have the potential to be simple and rapid tests for placed concrete. However, it is impossible to provide standard conditions for in-situ measurements. Water absorption is strongly affected by environmental temperature and relative humidity (RH). These different conditions may cause incorrect evaluation of concrete performance. Experimental measurements of water absorption were carried out over a range of relative humidity levels. Not surprisingly, water absorption increases significantly as the moisture content decreases. Surface relative humidity was found to have good correlation to sorptivity, decreasing the need for direct saturation determination.

1 Introduction

Long service life is an important issue for sustainability of construction materials. Concrete is the most widely used construction material, and its durability has importance as high as its mechanical properties. The main reason for concrete corrosion is penetration of corrosive materials through the cover zone. Most of these materials are dissolved in water, thus one of the most promising evaluations regarding concrete durability is water penetration based tests, which usually are used indirectly to evaluate concrete durability. It was found that in-situ permeability tests give much more reliable evaluation than an in-situ strength tests in order to evaluate durability properties of concrete (Long 1983). These water penetration based tests can be classified into two groups (Torrent and Luco 2007):

1. Permeability methods: Water permeability is water flow through a saturated homogeneous material under externally applied pressure which can be described by Darcy's law in Equation 1 (Goual 2000).

   [1] $$\vec{u} = -K_s \nabla P$$

   where:
   $\vec{u}$: Vector flow velocity
   K_s : Conventional saturated permeability
   ∇P : Potential pressure head gradient

2. Sorptivity methods: Water absorption, or sorptivity, is water flow in unsaturated porous materials due to pressure differences caused by capillary and gravitational forces. This capillary transport can be described by extended Darcy equation presented in Equation 2 (Kaufmann 1997).

[2] $$\vec{u} = -K(\theta)\nabla\psi$$

where:
ψ : Capillary potential
$K(\theta)$: Unsaturated permeability

Capillary potential is highly dependent on the volume of empty pores which are able to absorb fluid. Relative humidity and concrete moisture content affect the volume of empty capillary pores (Castro et al. 2011). So it can be concluded that concrete moisture content has a significant effect on water absorption rate.

The rate at which water is absorbed into concrete by capillary suction can provide useful information related to the pore structure, permeation characteristics and durability of the concrete surface zone that is penetrated (Parrott 1992). There are a few standard methods for water absorption measurement, which most are applicable only in the laboratory. For instance, ASTM C1585 proposes a standard conditioning which intends to provide an internal relative humidity similar to that found near the surface in some field concrete structures which is about 50% to 70% (ASTM C1585). Unfortunately, it is impossible to keep concrete's relative humidity in this range for in-situ measurements. Lack of a non-destructive, in-situ standard method for such an important measurement usually causes non-valid evaluations about concrete durability. As mentioned above, one of the most important factors which affect water absorption results in field measurements is the concrete moisture content. Changing of this parameter may cause different results for a same concrete element.

There have been several investigations in order to study the relationship between concrete moisture content and sorptivity. Research on the Figg Method showed a linear relationship between water content and Figg index (Figg, 1973). Basheer et al. (1995) also obtained a linear relationship between sorptivity and moisture content using the Clam test. The most practical study about influence of environmental RH on water absorption is authored by Nolan (1996) who found three linear dependencies of sorptivity for three different water to cement ratios based on the Autoclam water absorption method. Later, an outdoor exposure study by Basheer and Nolan (2001) showed a significant deviation between Nolan's (1996) linear equations and outdoor exposure data. It was concluded that in this subject the laboratory investigation was not directly transferable to in-situ measurements. A simple one-dimensional method similar to that of Hall (1989) was used by Nokken and Hooton (2002) to find a linear relationship between saturation degree and sorptivity based on one-dimensional water absorption. Castro et al. (2011) determined that initial sorptivity and total 8-day absorption based on the ASTM C1585 standard show a linear trend related to the RH in which the mortar samples were conditioned.

In this paper, the influence of concrete moisture content on concrete sorptivity is studied using a portable device suitable for lab or in-situ use. Concrete samples were manufactured and conditioned in 6 different moisture conditions. Moisture content measurements and water absorption tests were carried out on each specimen. Future plans include measurement of in-situ water absorption of the same concrete.

2 Experimental program

2.1 Materials used

Test specimens were manufactured using a concrete mixture of a bridge construction project in Montreal, QC, Canada. Specimens were obtained directly at the construction site, allowing the placed concrete to be monitored later for in-situ measurements with the laboratory results for calibration. The mixture design details and properties are as shown in Table 1. Chemical admixtures were added for workability, set control and corrosion resistance. Fresh concrete properties and compressive strength are presented in Table 2.

Table 1: Concrete mix proportion

Contents	Amount in 1 m^3	Unit
Cement type gub-SF	292	Kg
Fly ash Class F	73	Kg
Water	131	Kg
Crushed gravel 20 mm	585	Kg
Crushed gravel 5-14 mm	390	Kg
Sand	819	Kg

Table 2: Concrete properties

Maximum nominal aggregate size mm	Air content	W/C ratio	Slump (without plasticizer) mm	Slump (with plasticizer) mm	28 days compressive strength MPa
20	6.5%	0.40	80	140	35

2.2 Specimens details

The weight loss measurements required a relatively small sample so that small changes in weight could be measured accurately. Basheer et al. (1995) found out that specimen sizes do not affect the sorptivity index over the test duration of 20 minutes. However, its recommended for concrete specimen thickness to be larger than 50 mm and for edge distance (the distance between the edge of the specimen and the outer edge of the base ring) to be greater than 40mm (Basheer et al. 1995).

In order to have optimum sample sizes considering the test device dimensions, eighteen cylindrical molds of size 75mm height and 150mm diameter were manufactured for preparing the test specimens. The concrete was compacted in one layer by rodding 25 times

2.3 Specimens curing and conditioning

The specimens were stored at the project site with water curing for one week to be in the same situation as the main project concrete element. After, they were moved to an open field position which had the same weathering condition as the project site for three weeks. Then they were moved to laboratory and were unmolded and exposed to the conditioning regime.

Initially all specimens were saturated by incremental immersion over a period of 3 days. In order to simulate uniaxial water flow during the sorptivity test, samples were removed from water and the bottom face and round sides of specimens were painted by epoxy glue to be water resistant. Drying of the specimens was carried out in a fan assisted drying cabinet. Samples were placed to dry (at 45°C) for periods of 2, 3, 5, 7, 10 and 14 days to obtain six different moisture contents in the concrete. The temperature was selected to provide gradual drying without microstructural damage. After drying, the specimens were wrapped in plastic sheet and left for a period of one month in the laboratory to minimize the moisture gradient in the concrete cylinders. During this time, it was expected that the moisture in the capillary pores of the concrete would become well distributed through the specimen’s depth. This exceeds the 15 day period recommended in ASTM C1585.

In order to obtain dried weight of the samples, the specimens were subjected to be oven drying for three days at 110°C once sorptivity testing was completed.

2.4 Specimens testing

The following indexes were used to evaluate the concrete moisture content:

1. Initial saturation was determined by weight measurements taken after the epoxy painting process (saturated surface dry weight, W_{SSD}) and before testing (W_{TEST}) and after oven drying stage (W_{DRY}). The saturation degree determined using Equation 3.

$$[3] \qquad Saturation = \frac{W_{TEST} - W_{DRY}}{W_{SSD} - W_{DRY}}$$

2. Relative humidity measurement. Relative humidity measurements were carried out at the test surface of concrete specimens using a humidity measuring device. A commercial humidity indicator, Vaisala HUMICAP indicator HMI41and its probe HMP45 was used for this approach. As it is shown in Figure 1, the RH probe measured the relative humidity of the air above the concrete surface sealed in the GWT 4000 chamber which was installed on the specimen top surface. After various times, depending on samples moisture content, the humidity of the sample and surrounding air reached to the equilibrium stage. In this study, the RH probe should be left for a period between 90 min to 2 h to arrive at a stable reading RH. This value could be considered as the concrete surface relative humidity. This method of concrete RH measurement was used in previous studies (Nolan 1996, Basheer 2001).

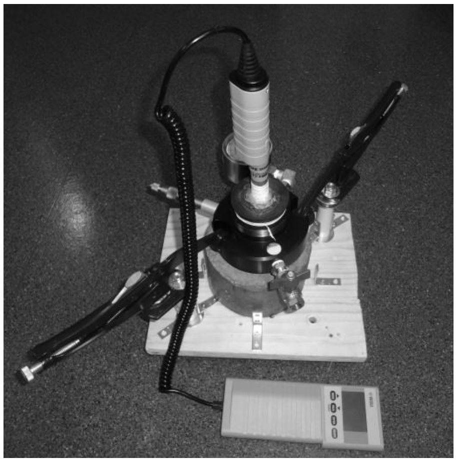

Figure 1: Specimen surface relative humidity measurement

Sample sorptivity was measured after the RH measurement for each sample. This measurement was carried out using a commercial apparatus, GWT 4000 developed by Germann Instruments. A sealed pressure chamber is attached to the concrete surface, boiled water is filled into the chamber and a required water pressure is applied to the surface. The pressure is kept constant using a micrometer gauge with an attached pin that compensates for the water leaving the chamber, to measure the amount of water penetrating the substrate. The difference in the gauge position over a given time is taken as a measure of the water penetrability for given water pressure (GWT-4000 Instruction and Maintenance Manual, 2010).

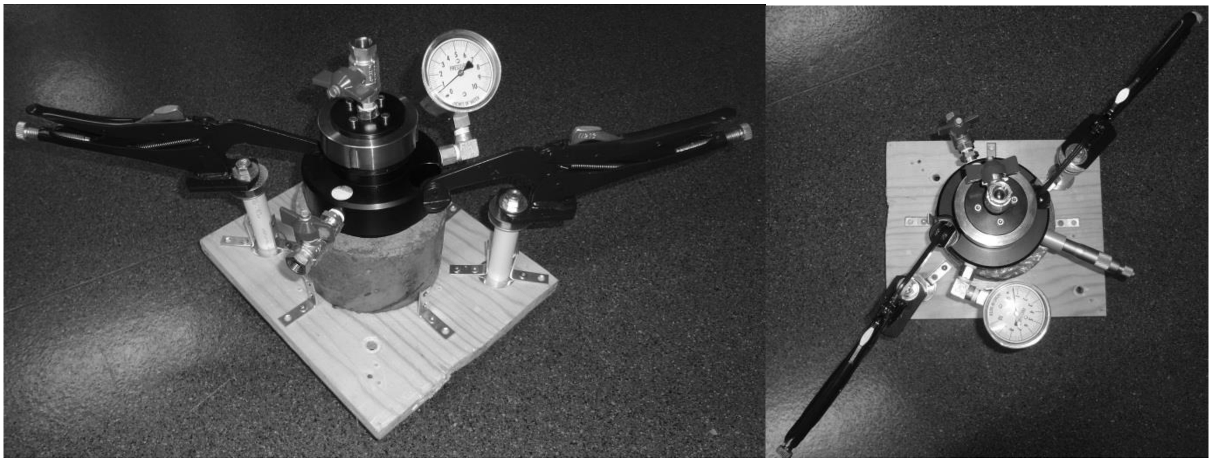

Figure 2: Water absorption test using GWT-4000

The recommended water pressure for this sorptivity test is 0.01 bar. At this pressure head, it can be assumed that all water absorbed by the specimen surface is due to concrete capillary suction (Basheer, 1995). It is also recommended to consider 2 minutes for an initial time delay in starting the test after water first is introduced into the test area (Basheer, 1995). This time delay was recommended to be 10 min by the device instruction manual. In this study, it was found out that 5 min initial delay is enough to obtain a linear relationship for cumulative absorption over square root of time. Regarding the test duration, it was decided to use 20 minutes because it was observed that a test lasting for 20 minutes would yield sufficient number of data points in order to calculate the sorptivity index. The tests were done in laboratory environment at a constant temperature of 22±1°C. Figure 2 shows the test set-up with a specimen in place.

Concrete cumulative absorption was obtained using Equation 4 (GWT-4000 Instruction and Maintenance Manual, 2010).

[4] $$I = \frac{B.(g_1 - g_2)}{A}(mm)$$

Where:
I: Cumulative water absorption
B: Area of the micrometer pin being pressed into the chamber, 78.6 mm^2 for the 10 mm pin diameter.
g_1 and g_2: The micrometer gauge reading in mm at the start of the test and after specified times.
A: The water pressure surface area, 3018 mm^2 for 62 mm gasket inner diameter.

Figure 3 shows typical values of cumulative water absorption versus square root of time for one of the samples. The Sorptivity index can be calculated as the slope obtained by using least squares linear regression analysis of the plot. All specimens yielded similar linear results with high correlation.

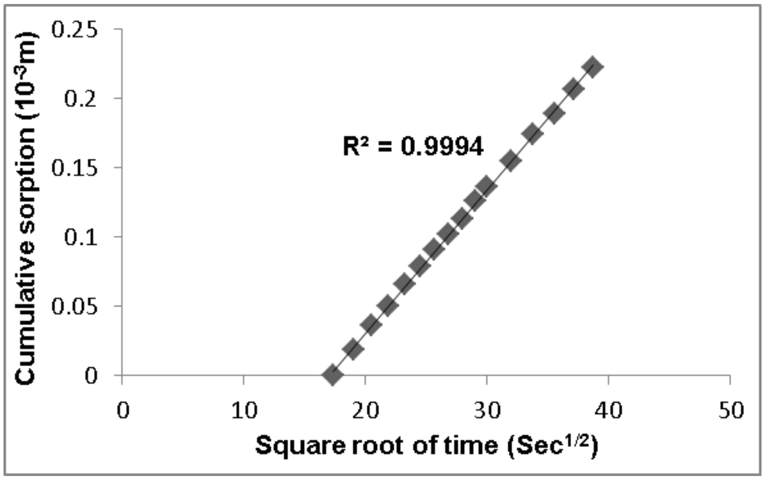

Figure 3: Typical cumulative absorption versus square root of time after 5 minutes of initial delay

3 Results and discussion

In order to obtain more reliable results, three samples were manufactured for each condition. The results presented below are the average value of three test iterations.

3.1 Moisture content variation

Figure 4 shows the concrete saturation versus the square root of the duration of drying under the mentioned conditions. Obviously the saturation degree decreases with increasing of drying duration. It suggests a linear relationship between saturation degree and square root of drying duration. This result was also obtained in previous research. This relationship can be described by a falling drying rate where the drying rate is limited to the rate of unsaturated water flow towards the drying surface (Nolan, 1996). This relation is the same as water flow through unsaturated concrete due to capillary suction (Hall et al., 1984). The slope of this trend is related concrete structure properties.

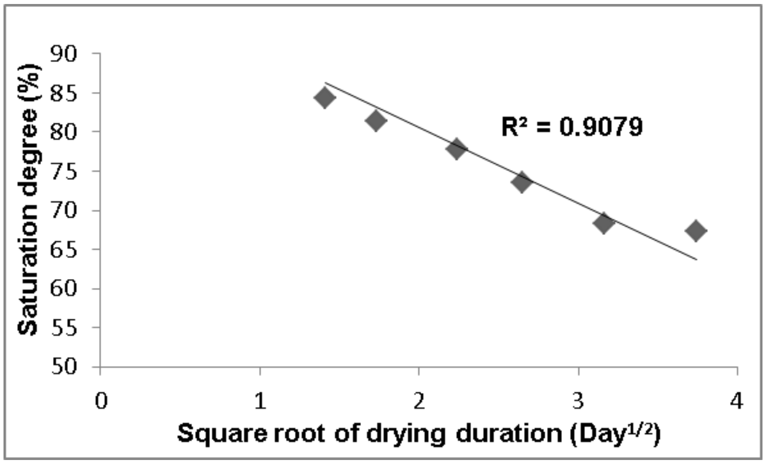

Figure 4: Saturation degree versus square root of duration of drying

The relative humidity measurements were done using the described method. The final RH values of the sample's surface are shown in Figure 5 against square root of drying period. This shows also a linear trend over square root of drying duration. This same relationship is presented in Nolan (1996).

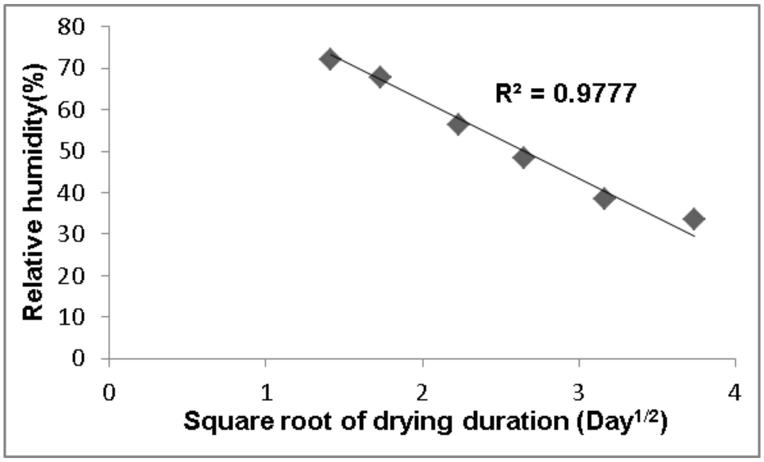

Figure 5: Concrete surface relative humidity versus square root of drying duration

Figure 6 shows the linear relationship between RH values and saturation. This shows that RH measurement values can be used as reliable index for concrete moisture content, enabling in-situ measurements. It is obvious that concrete moisture gradient over the samples depth affects surface RH results.

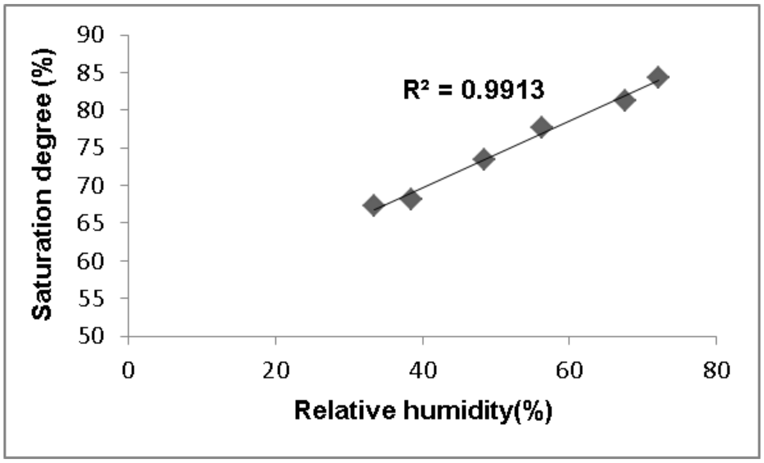

Figure 6: Relationship between concrete saturation degree and surface relative humidity

3.2 Sorptivity variation

Sorptivity decreases with increasing saturation as is shown in Figure 7. This is because of the loss of moisture from the capillary pores in the concrete which leaves capillary pore space free to absorb moisture into the concrete. Theoretically, a fully saturated concrete could be expected to show no water absorption and due to this, the linear regressions were forced through this point in the analysis. This result was also found by Nokken and Hooton (2002). Other studies show the same linear trend; sorptivity increases with decreasing concrete moisture content (Hall 1989, DeSouza 1997 and Castro et al. 2011). Other approaches using Autoclam sorptivity test device and Figg's absorption test method have been came out to a similar conclusion (Basheer et al. 1995 and Figg 1973)

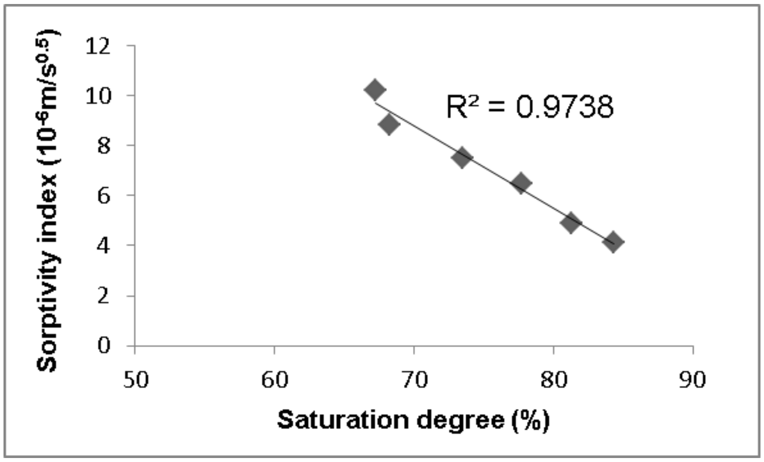

Figure 7: Effect of concrete saturation on sorptivity index

Dependence of sorptivity on RH values is presented in Fig. 8. Theoretically, this relationship could be expected to pass through 100% RH and zero sorptivity. It shows a linear trend between the sorptivity index and RH measurements values. Sorptivity index decreases as the concrete surface relative humidity increases. Previous studies show the same linear trend between 10 mm depth RH value and concrete sorptivity (Nolan 1996). But it was not verified by outdoor exposure concrete samples due to difference of percentage of hydrated cement in laboratory samples and in-situ concrete (Basheer 2001).

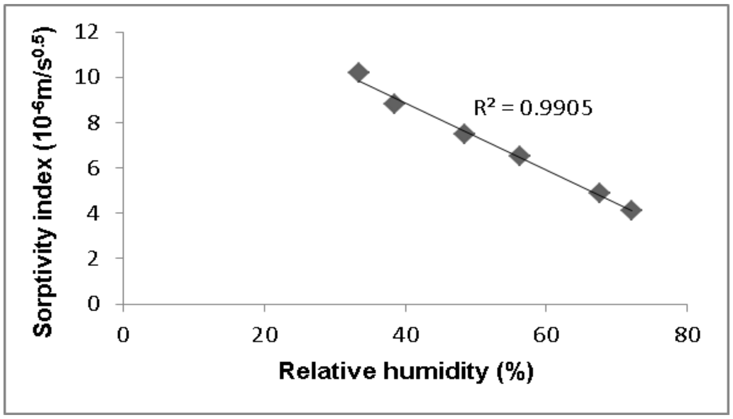

Figure 8: Relationship between concrete surface relative humidity and sorptivity index

4 Conclusion

Concrete durability is the most significant concrete property after its mechanical features. One of the possible non-destructive tests regarding concrete durability evaluation is water absorption. This test gives various results with the same concrete in different conditioning situations. This leads to obvious misleading evaluations limiting its practical use in the field. To date, the study of Basheer and Nolan (2001) is the only published source of in-situ measurements, but with poor correlations to lab results necessitating further research.

This paper studied the relationship between sorptivity and concrete moisture content measured by two different indices; saturation and surface relative humidity. This investigation was carried out by testing on 6 different moisture content stages. Although similar research has been performed regarding concrete absorption dependence on moisture content but that of Nolan (1996) offered a practical solution to measure moisture for in-situ measurements. This paper used surface RH measurement which is a feasible approach, in order to evaluate the moisture level of concrete in the field, where gravimetric methods are impossible.

The following conclusions can be made from the test results:

1. Saturation degree decreases as the drying duration increases. Concrete saturation degree has a linear trend with square root of drying period.
2. Concrete surface relative humidity decreases as the drying period increases. RH values show a linear relationship with the square root of drying duration. It also shows a linear dependence with concrete saturation. Indicating that relative humidity of concrete surface (if there is no moisture gradient in concrete depth) can be used as a reliable index for concrete moisture content.
3. Concrete sorptivity index shows a significant dependence on concrete moisture content. Concrete sorptivity decreases as the both concrete surface RH and saturation increase.
4. Overall, it can be concluded that sorptivity measurements vary with concrete moisture content. It is suggested to measure the concrete RH value, which is more practical than saturation for field measurements in conjunction with the sorptivity test and consider it in concrete durability evaluation using related correlation scales. This can lead to a more accurate evaluation of concrete durability.

5 Acknowledgment

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