REPORT

Contact person RISE
Patrick Rogers
RISE CBI Swedish Cement and
Concrete Research Institute
+46 10 516 68 45
patrick.rogers@ri.se

Date
2018-11-19

Reference
8P05884 ver 1.3(eng)

Trollhättan Mineral AB
Martin Zetterstedt
Stallbackavägen 7
461 38 Trollhättan
SWEDEN

Comparison of internal relative humidity between HPC 100 concrete and reference concrete at 20°C & 50% RH

(4 appendices)

Assignment

RISE CBI was commissioned by Trollhättan Mineral AB to compare and measure the internal relative humidity in three concrete slabs that were exposed to one sided drying in a constant controlled environment (20°C & 50% ± 2 RH). The measurements were carried out over a period of ca. two months, i.e. from 22/06/2018 – 20/08/2018.

Three uncovered concrete slabs with measurements 0.5 m x 0.5 m were transported to RISE CBI (East) one day after casting (21/6/2018). The concrete slabs were produced and transported by the client. The concrete slabs were of two types, a reference concrete "REF" with a thickness of 0.2 m and two high performance concretes "HPC 100" with two thicknesses 0.1 m and 0.2 m. The molding materials were of plywood and covered the entire surface of the slab except the quadratic casting surface. Attachments to aid lifting (rebar) were cast into the fresh concrete, see Figure 1, Figure 2 & Figure 3.

According to the client, the reference concrete "REF" was produced on the client's premises. A pre mixed bag of "GROVBETONG" from weber (part of the Saint Gobain group) was used. According to the manufacturer this concrete can be a C32/40 if mixed in the correct proportions. The maximum aggregate size = 12 mm. The contents or attributes, e.g. water to cement ratio, of the HPC 100 concrete were not disclosed by the client.

RISE CBI (East) maintains no responsibility for the production, post treatment or transport of the concrete slabs to the laboratory.

Figure 1. Reference concrete "REF". The "+" signs mark the positions where the measurement holes were to be drilled. The dimension of the concrete is 0.5 m x 0.5 m. The thickness of this slab is 0.2 m.

Figure 2. HPC 100 concrete slab. The dimensions of the surface area is 0.5 m x 0.5 m .This slab is 0.1 m thick. Note the rebar in the middle, this was cast in order to aid the weighing.

Figure 3. HPC 100 concrete slab. The dimensions of the surface area is 0.5 m x 0.5 m .This slab is 0.2 m thick.

Method

The method of measuring internal humidity in concrete in Sweden has been agreed upon by Sveriges Byggindustrier (Swedish Construction Federation) and approved by "Rådet för ByggKompetens" (RBK) (Rådet för Byggkompetens, 2018). The version used in this study is version 6 and has been valid since 9/10/2017 and is subject to copyright.

The slabs were covered with plastic once these arrived to the laboratory at RISE CBI. These were then weighed before and after measurement holes were drilled. The drilling holes were planned and carried out according to RBK's technical documents (see above). The drill hole depths equated to 0.4 of slab thickness, see Figure 4.

The first drill holes were completed on 22/06/2018. The holes were placed 10 cm from the edges at a depth of 0.4 of slab thickness, i.e. either 4 cm or 8 cm. The plastic applicators were sealed with accordance to RBK's product requirements. These applicators were used to expose the concrete at that particular depth in conjunction with the measurement sensor. This forms a sealed volume of air in contact with the concrete. Two holes were drilled in the reference concrete slab "REF".

The concrete slabs were placed on two standard pallets (120 cm x 80 cm) whilst in the climate room (20°C & 50% ± 2% RH). The temperature of the concrete was assumed to be 20°C.

The relative humidity measurement device used was a VAISALA HM40. The measurement sensors, HMP110, are from the same manufacturer. Their calibration certificates are in APPENDIX 3. These sensors were placed in the plastic applicators 25/6/2018, i.e. 3 days after the holes were drilled. The entire weight of the concrete slab including measuring devices was measured. The first relative humidity measurements were taken 2 days after the RH sensors were placed in the concrete (27/6/2018). Measurements were taken daily thereafter. See Table 1 for where RH sensors were placed.

According to RBK rules, a measurement hole may not be used for data 10 days after it was drilled; in this case after 1/7/2018. In order to reduce the amount of drill holes and to cover the period up to 28 days after casting, new holes were drilled 9/7/2018 in all concrete slabs.

The same procedure of preparation work for the sensors was carried out for the new measurement holes.

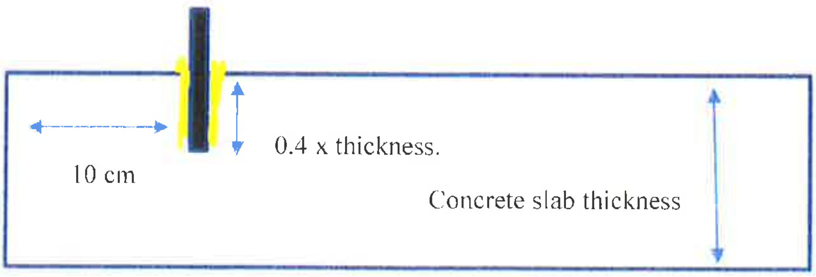

Figure 4. The schematic represents the side view of the concrete slabs with the measurement hole and the sealed plastic applicator (black). The yellow mass around the plastic applicators indicates the sealant. The concrete slabs is sealed from all sides by the plywood molding (not seen in the schematic).

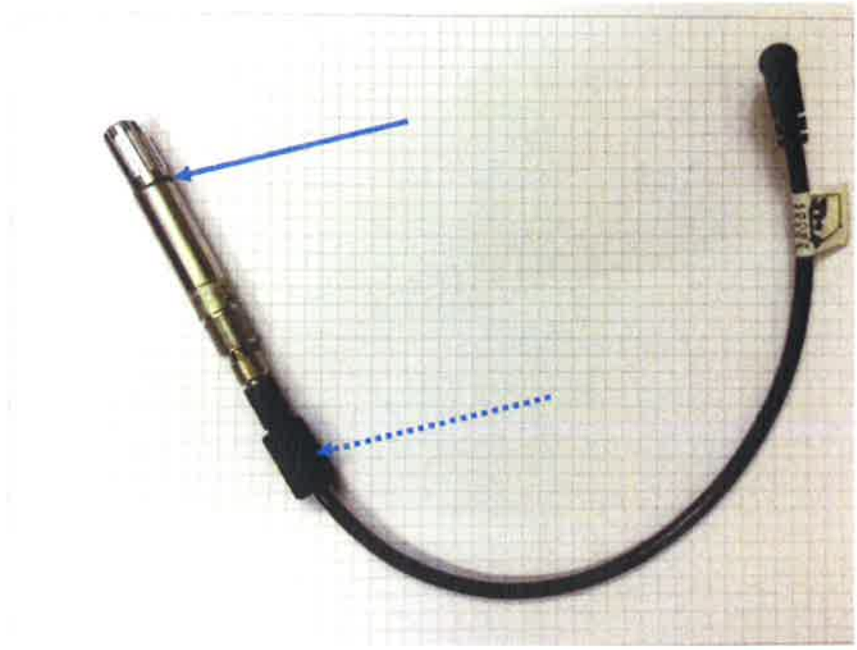

Figure 5. Photo of VAISALA HMP110, the same type of measuring sensor used in the study. Note the rubber stopper (dotted arrow) which seals the air in the plastic applicator and the O-ring (full arrow) on the sensor which seals the air directly in contact with the concrete from the rest of the air in the plastic applicator.

Table 1. VAISALA HMP110 sensors used in the experiments, the "-" is part of the identifying number on the sensor. During the experiments a new hole had to be drilled and the sensor had to be moved, this is denoted with "new hole" in the parentheses.

Concrete	Sensor	Sensor (new hole)
HPC 100 (10)	"-7"	"-7"
HPC 100 (20)	"-6"	"-6"
REF 1 (20)	"-4"	"-4"
REF 2 (20)	"-8"	"-8"

"REF 1" & "REF 2" are in the same concrete slab, but indicate different holes.

RESULTS

Firstly, the results show the observed value, i.e. the digital value obtained from the measuring device, see Figure 6. Several other factors are taken into consideration before one can obtain a value closer to the true value of internal relative humidity.

The weight loss data is shown in Figure 7.

After the experiment, a post experimental check on the sensors was carried out and how these affect the results in this experiment is summarized in Table 4 and the graphs can be seen in APPENDIX 1 all figures.

Sensor "-8" , in "REF (20)" [grey circles] was only used for indication purposes only. No post experiment control was carried out for this sensor. There were two RH sensors in the reference concrete.

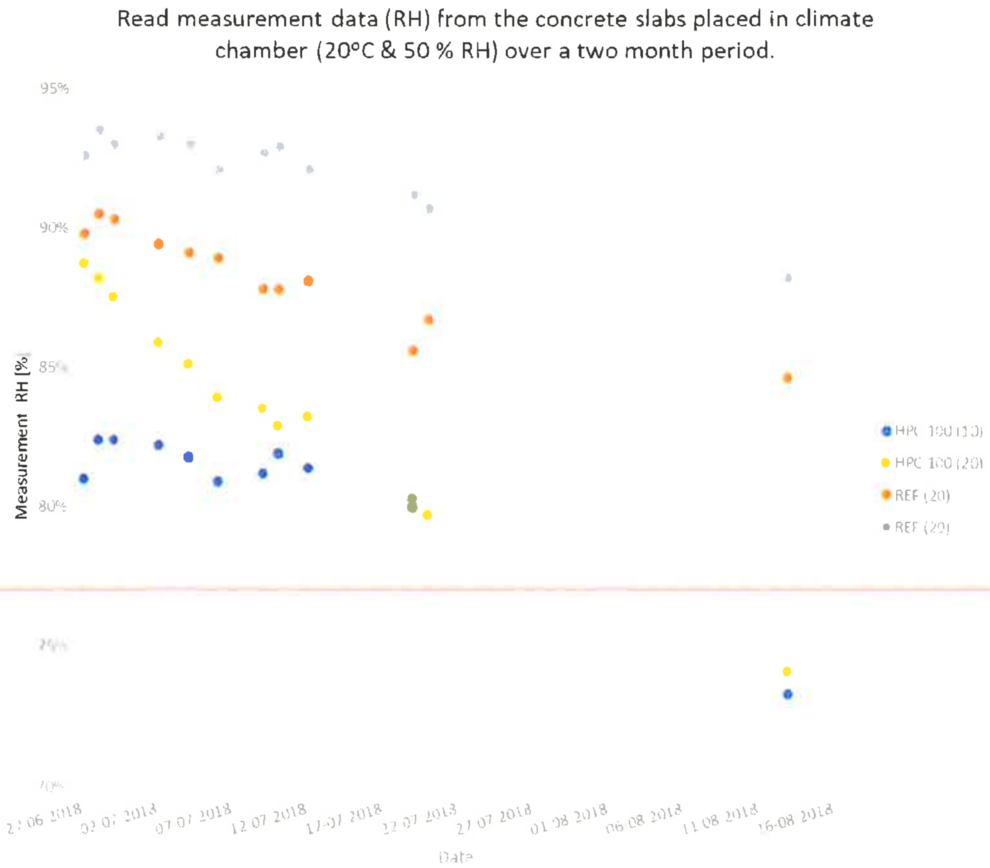

Figure 6. Observed RH values from the measurement device in the different concrete slabs.

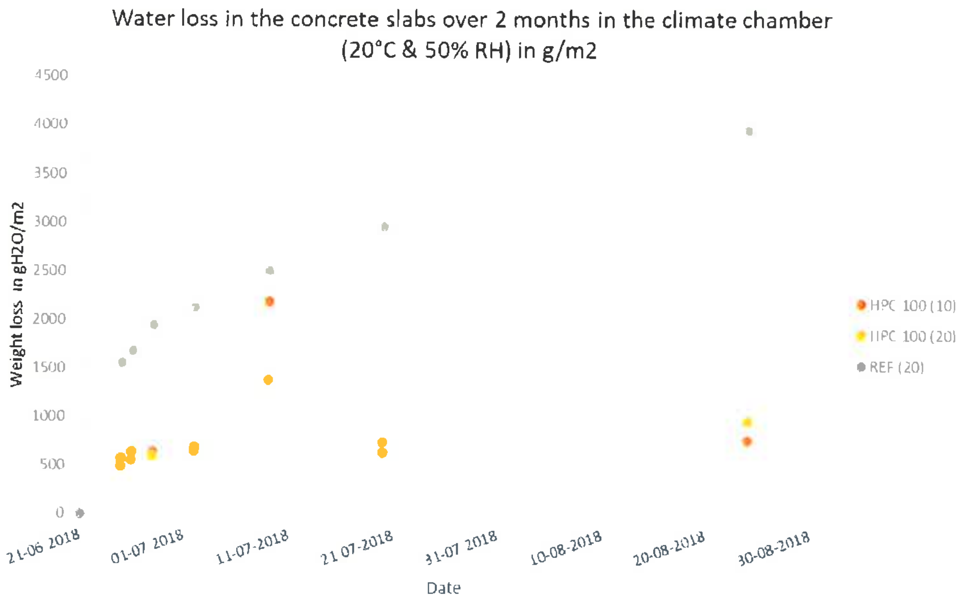

Figure 7. The weight loss observed from one measurement interval to the next during the experiment. Note the deviation observed in both HPC 100 concretes approx. three weeks after the concrete was cast.

Observed Results

Table 2. Directly observed data from the measuring device. These are within the tolerance set by RBK. Note these values have no measurement errors included and are not valid.

	[RH in %]	[RH in %]	[RH in %]
Specimen (thickness in cm)	cast + 8 days	cast + 11 days	cast + 28 dygn
HPC 100 (10)	82.4	82.2	80.0*
HPC 100 (20)	88.2	85.9	80.3*
REF 1 (20)	90.5	89.4	85.6*
REF 2 (20)	93.5	93.3	91.2*

"REF 1" & "REF 2" are in the same concrete slab, but indicate different holes.

*New hole due to RBK recommendations

Conversion of observed results to real results with a higher level of confidence.

Real Internal [RH] = Observed Measurement [RH] + measurement errors + post experiment sensor control.

Using the diagrams, see APPENDIX 1 from the post testing control, the observed values from Table 2 are converted partly to the "real" internal RH values.

The post experiment sensor control consists of exposing the sensors to stable saturated salt solutions which have differing RH values. The observed value from the measurement device is compared to the true value (from the stable saturated salts).

Table 3. Value [RH] added to the observed value [RH] from Table 2, based on post experiment check, see APPENDIX 1. Specific to three occasions where the RBK criteria are fulfilled.

Sensor	Cast + 8 days	Cast + 11 days	Cast + 28 days
"-4"	+2.1	+1.7	-1.2
"-6"	+1.3	0.0	+1.3
"-7"	+2.6	+2.8	+2.5

In addition to all observed results, an additional measurement error factor of + 2.7% (see APPENDIX 4) plus +0.5% (see APPENDIX 4) are added.

Together these values result in Table 4 below and are used in the discussion.

Real Internal Humidity

Table 4. Real internal relative humidity [RH] values according to RBK rules. Corrected values from Table 2 including all relevant measurement errors and post experiment sensor check.

	[RH in %]	[RH in %]	[RH in %]
Specimen (thickness) [sensor]	cast + 8 days	Cast + 11 days	Cast + 28 days
HPC 100 (10) ["-7"]	88.2	87.7	85.7
HPC 100 (20) ["-6"]	92.7	88.6	84.8
REF 1 (20) ["-4"]	95.8	93.8	87.6
REF 2 (20) ["-8"]	96.7	96.5	94.4

Compressive Strength

Table 5. Compressive strength testing of 100 mm sided cube. The figures "7" or "28" in the specimen column indicate the age of the concrete in days at testing.

	Weight	Max Force	Compressive strength
Specimen	[g]	[kN]	[MPa]
HPC 100 7d	2655	955.9	95.6
HPC 100 28d 1	2663	1559.0	155.9
HPC 100 28d 2	2665	1120.0	112.0

Weight Loss

Table 6. The cumulative weight loss per m² concrete area (exposed) after 29 days at constant climate (20°C & 50% RH).

Specimen (thickness in cm)	gH_2O after 29 days/m²
HPC 100 (10)	636.4
HPC 100 (20)	744.4
REF (20)	2952.8

No measurement error for the weight loss procedure was included in the calculations.

Discussion

The weight loss and internal relative humidity in the concrete slabs were measured with an acceptable time interval over a total of 2 months according to the guidelines of RBK. The HPC 100 concrete, with a thickness of 20 cm, reached an internal relative humidity of under 85% after 28 days. This included all the measurement errors and post experimental checks required by RBK. The HPC 100 concrete with a thickness of 10 cm was 0.7% above the desired value of 85%. The reference concrete had an internal relative humidity of 87.6% when exposed to the same conditions, see Table 4 for all the results.

The weight loss of the concrete slabs showed a big difference between the two concretes, see Figure 7. The reference concrete lost nearly 4 times the amount of water vapour as the HPC 100 concretes, see Table 6. An increased weight loss was noted around 11/7/2018, approx. three weeks after the concretes were cast.

The compressive strengths, see Table 5, show that the HPC 100 concrete is a high performance concrete based on the amount of samples that the laboratory tested. The concrete has most likely a low water to cement ratio (w/c). The amount of water that is chemically bound to the cement hydration products is unknown, but generally the lower the w/c, the less water vapour that can be driven out of a concrete in a normal environment. This would help explain the weight loss differences between the reference concrete and the HPC 100 concrete.

No reference concrete samples for compressive strength testing were delivered by the client.

RISE Research Institutes of Sweden AB
RISE CBI Swedish Cement and Concrete Research Institute - CB East

Performed by | Examined by

Patrick Rogers | Annika Gram

Reference

Rådet för Byggkompetens, 2018. *RBK website.* [Online]
Available at: http://rbk.nu
[Accessed November 2018].

Appendices

1 Measurement of the difference in known RH (saturated salts] and observed RH [device + sensor] at different intervals [cast +8 ;+11;+28 days]. [in Swedish]

2 Post experiment control on sensors with saturated salts. [in Swedish]

3 Calibration certificates for the sensors. [in Swedish]

4 Measurement Errors