SHUTE Sensing Solutions A/S

Measurements of relative humidity using FBG sensors

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Abstract

This white paper aims to demonstrate that SHUTE sensors can measure humidity during the drying of concrete and that the SHUTE sensor measuring capability is not affected by water, even after being submerged in water for 14 days. In order to demonstrate this, 3 separate sensors have been calibrated with salt mixtures, each salt representing a specific Relative Humidity (RH) level. Moreover, one sensor has been tested for water resistance by characterizing the response of the sensor before and after it was immersed in water for 14 days. After calibration, the sensor was prepared for casting in concrete. The sensor fiber lead was protected with first a plastic tube and then a steel tube. A sensor was housed inside a stainless steel pipe and a Gore-Tex® membrane was used as a permeable membrane in order for the sensor housing to equalize with the moisture in the concrete.

The sensor was cast in concrete and left measuring the drying of the concrete over several days. The RH measurements are compared to the RH measurements of a Vaisala HM40 and it is demonstrated that the SHUTE sensor can withstand the wet concrete and measure the drying of the concrete.

Introduction

The SHUTE Fiber Bragg Grating (FBG) sensors, are able to measure stress, strain and humidity. In particular, the focus of this work is to demonstrate that they could be a valuable tool for measuring humidity inside concrete during the drying of the concrete. Measuring the humidity level in the concrete is essential for time and energy optimization. And in order to have precise knowledge on how a concrete structure is drying, it is necessary to have ”eyes” inside the concrete. The sensor will have to withstand a wet environment and still measure accurately. This will enable precise knowledge on how a concrete structure is drying and optimize the timing as to when the structure is ready for wooden/linoleum floors, paintwork and/or plaster walls to be installed. This is why it is crucial to demonstrate that SHUTE sensors are able to measure RH in concrete.

Sensors Calibration

It is important that the sensors are able to measure the same relative humidity (RH) in a reproducible manor. In order to demonstrate the reproducibility, three sensor calibrations are performed. To calibrate the sensors, they were kept in a closed environment with different salts mixture, each of them with different RH, and it is demonstrated that the sensors were measuring the same RH each time.

Calibration Setup

The sensors were inserted into PE bottles. In the lid of the bottle, a hole was made and a flexible mechanical joint was glued on top of it. In this way the sensors were protected and the humidity levels inside the PE bottles were not influenced by the external environment. The sensors were inserted through the protective tube and were able to make measurements inside the bottle.
A picture for the setup is shown in figure 1:

Figure 1: Picture of the PE bottles with salt mixtures inside.

Salt Mixtures

The sensors have been calibrated using different salt mixtures [1], namely:

- Lithium Chloride ($LiCl$), with relative humidity (RH) of 11.30 at $25°$C
- Magnesium Chloride ($MgCl_2$), with RH of 32.8 at $25°$C

[1] L. Greenspan, *Humidity Fixed Points of Binary Saturated Aqueous Solutions*, J Res Natl Bur Stand A Phys Chem: Vol. 81 A , No.1 (1976)

- Magnesium Nitrate ($Mg(NO_3)_2$), with RH of 52.89 at $25°$C
- Sodium Chloride ($NaCl$), with RH of 75.29 at $25°$C
- Potassium Chloride (KCl), with RH of 84.34 at $25°$C
- Potassium Sulfate (K_2SO_4), with RH of 97.30 at $25°$C

The mixtures were prepared in the PE bottles shown in figure 1. In addition, temperature was recorded with a TESTO 184 T2 temperature data logger.

Calibration results

The plot in figure 2 show the calibration of three sensors, calibrated at different dates. The results are temperature compensated according to temperature variation. The slopes and the values of RH measured are very similar.

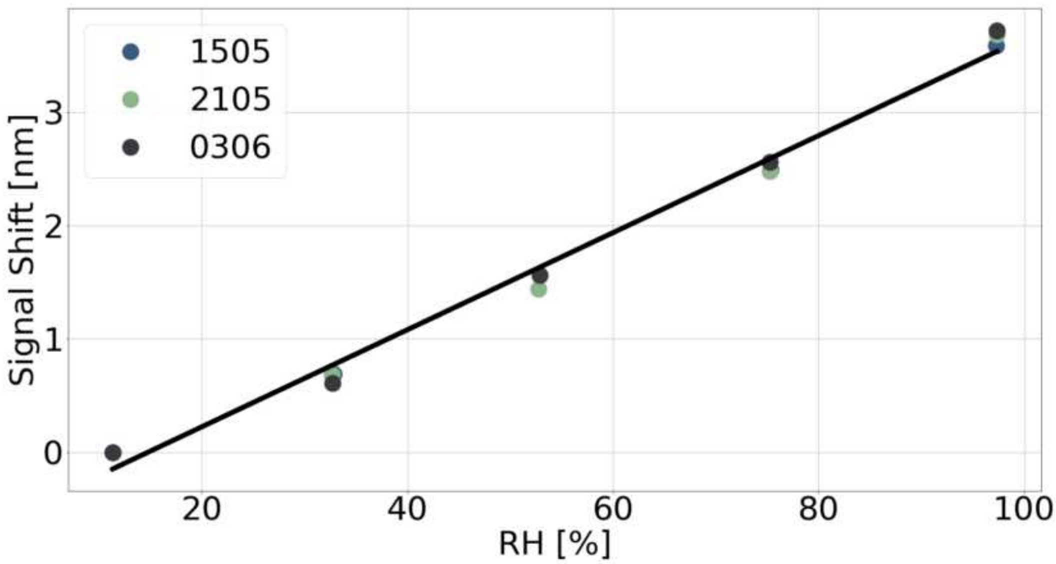


Figure 2: Results from calibration of three different sensors, calibrated on three different dates. The average sensitivity is: $0.041 \frac{\text{nm}}{\%\text{RH}}$

These three calibrations demonstrate the RH sensitivity and reproducibility of the SHUTE sensors.

14 days water test

Considering that during the process of concrete curing, the sensor will be in a very wet and humid environment, it is necessary to demonstrate that the SHUTE sensor

can survive in very humid or wet environments for a longer time period. To test this property, a sensor was first calibrated, then immersed in water for 14 days, and then calibrated again. The plots in figure 3 show the calibration results, before and after being submerged in water for 14 days. The sensor was able to measure the same values. This demonstrates that SHUTE sensors can be submerged in water for a long time period, without that affecting the precision or calibration of the sensor.
The tolerance to water is an essential characteristic of the SHUTE sensors. And it is a unique parameter differentiating SHUTE sensors from electrical humidity sensors. Normally, electrical sensors can not survive long periods of time immersed in water.

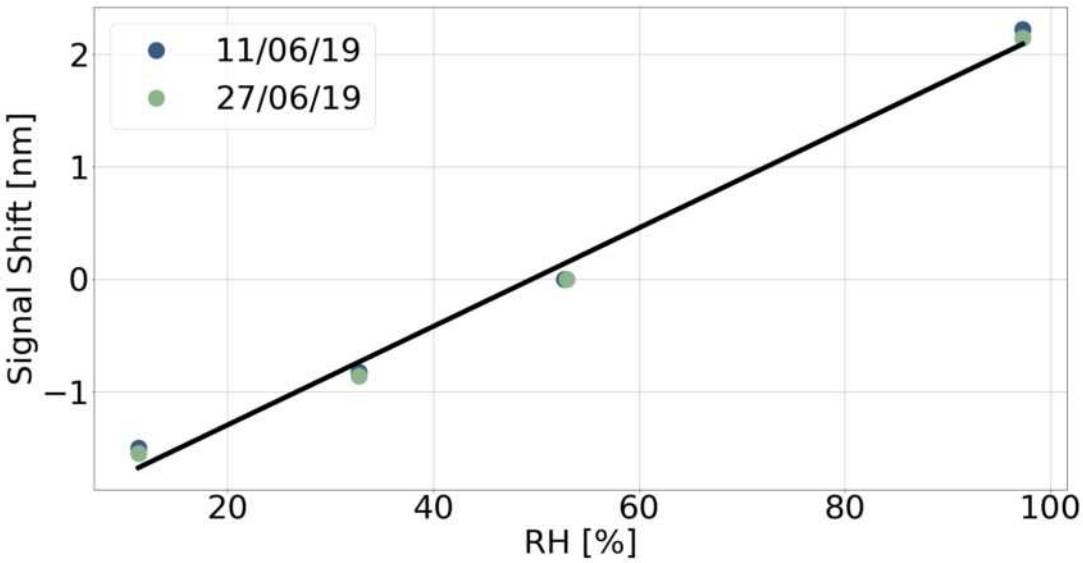


Figure 3: Linear fitting before and after 14 days water. The sensitivity of the sensor is: $0.044\frac{\mathrm{nm}}{\%\mathrm{RH}}$.

Concrete tests

Setup

Following the example set by Swanson *et al*[2], the setup used for casting the sensor in the concrete consisted of a $6\,\mathrm{cm}$ long stainless steel pipe, with a hole of $3\,\mathrm{mm}$ in diameter.

One end of the pipe was closed by a Gore-tex® Gasket membrane (GORE GR) $\varnothing\,4\,\mathrm{mm}$ and $1\,\mathrm{mm}$ thick. The membrane was fixated with a bolt nut.

In figure 4, a drawing of the sensor and the housing is presented:

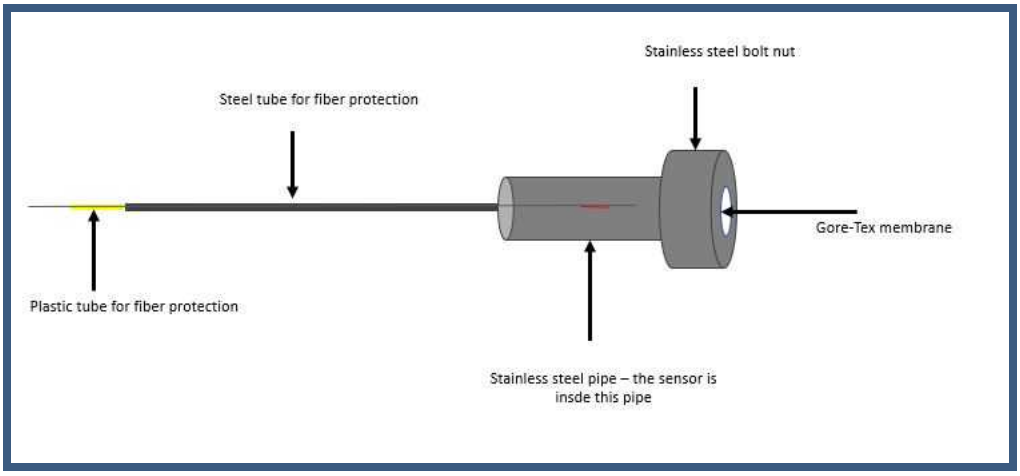
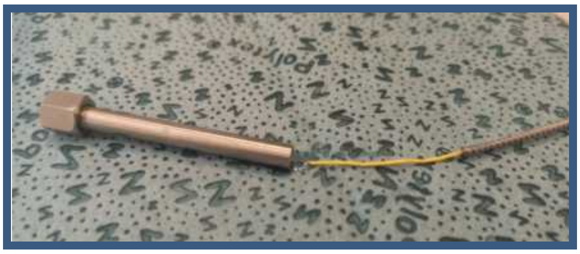


Figure 4: Scheme of the sensor housing.

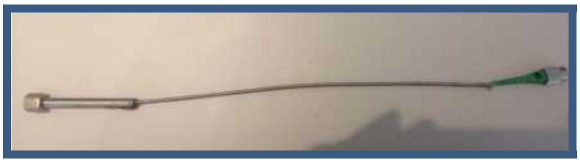
The sensor was inserted inside the stainless steel tube and the part of the fiber sticking out of the pipe was covered in a inner plastic tube and a outer steel flexible tube. Everything was glued with epoxy glue, such that the sensor could not move inside and air could not contaminate the environment inside the stainless steel tube. Pictures of the gluing process and the final version of the sensor with the tubes and the housing are presented in figure 5.

[2]A.J. Swanson, D. Bogunovic, J. Schuty, Y. Jia, S. Janssen, D. Carder, S.G. Raymond, *Fibre Optic Relative Humidity Sensors For Use In Concrete Structure*, The New Zealand Concrete Industry Conference, October 2017



(a)

(b)



(c)

(d)

Figure 5: Gluing process and final result. In (a) and (b) it is possible to see two different stages of the gluing; (c) and (d) are the pictures of the final product, seen from above and from the front.

This setup for concrete has been tested with the same salt mixtures used for the calibration and it is demonstrated that the sensor can still measure RH even through the Gore-Tex® membrane. Results for the calibration with the housing can be seen in figure 6:

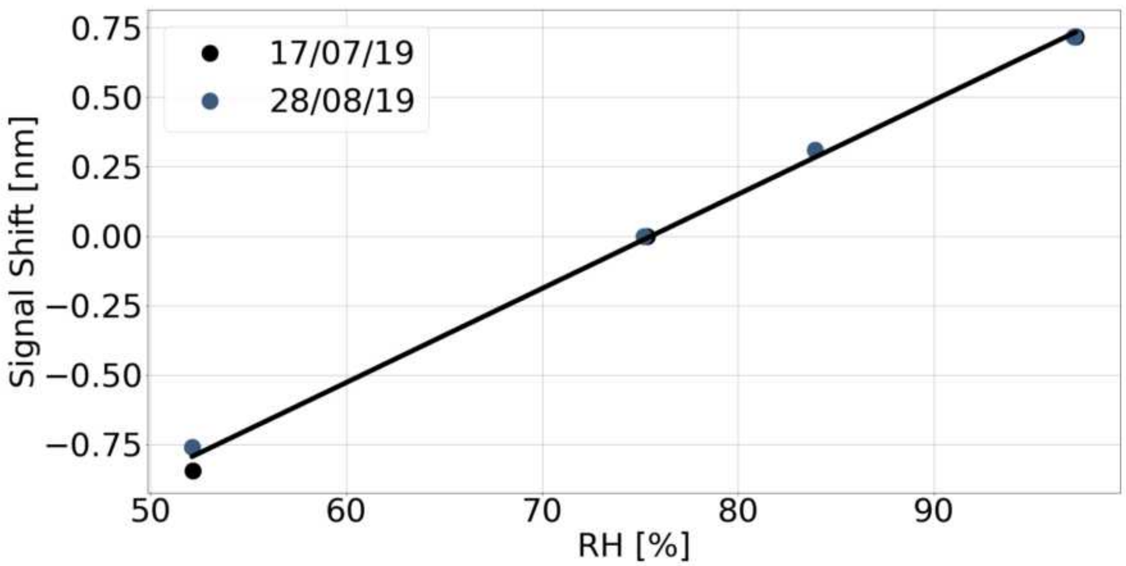


Figure 6: Calibration for the same sensor with protective housing. The characterization has been made twice in order to demonstrate that the housing is stable.

Test in concrete

After the calibration for the sensor housing, the sensor was cast in concrete. The composition used for the mixture were:

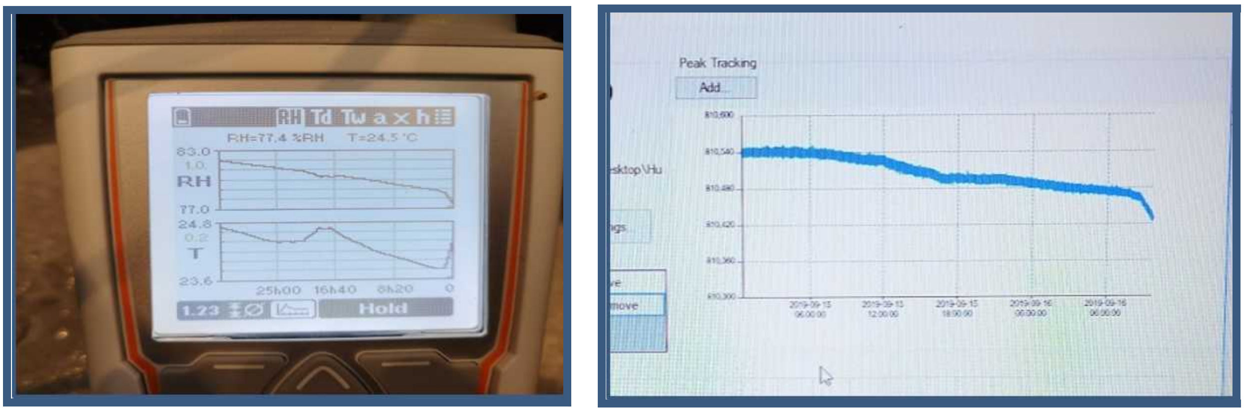
- Wet Sand 0-4 mm (3.5 parts)
- Portland Cement (1 part)
- Water (0.3 part)

For the test; 3 kg of concrete were mixed in a bucket of $20\,\mathrm{cm}$ in diameter. The exact quantity used of each material are 2.35 Kg of wet sand, 0.675 Kg of cement and 0.2 Kg of water. The sensor house was inserted into the wet concrete and left to monitor the drying of the concrete. A sensor house for the electric sensor Vaisala HM40, was also inserted into the wet concrete. The Vaisala sensor was being used as a reference for the measurements but it could not be cast into the concrete while the concrete was wet, because the mixture was too wet for an electric sensor to survive.

Figure 7: Image of the dry concrete with the Vaisala HM40 probe and the SHUTE sensor inserted into the concrete.

Results

During the measurements, there was observed an almost identical behaviour of the SHUTE sensor and the Vaisala sensor. A visual image of this behaviour can be seen in figure 8a and in figure 8b. In the picture you can see how the top graph shown by the Vaisala sensor, the one for RH, follows exactly the pattern of the SHUTE sensor.



(a) (b)

Figure 8: Comparison between Vaisala and the SHUTE sensor measurements. It can be seen that the behavior of the Vaisala sensor (top plot in image (a)), is the same as for the SHUTE sensor (b). This demonstrates that the two sensors were measuring the same humidity variations at the same time.

After roughly 9 days, the concrete reached a stable level of humidity. The raw data from the SHUTE sensor, shows a decrease in humidity in a range that was expected.

The graph with the raw data can be seen in figure 9 where the measurements have not been temperature compensated:

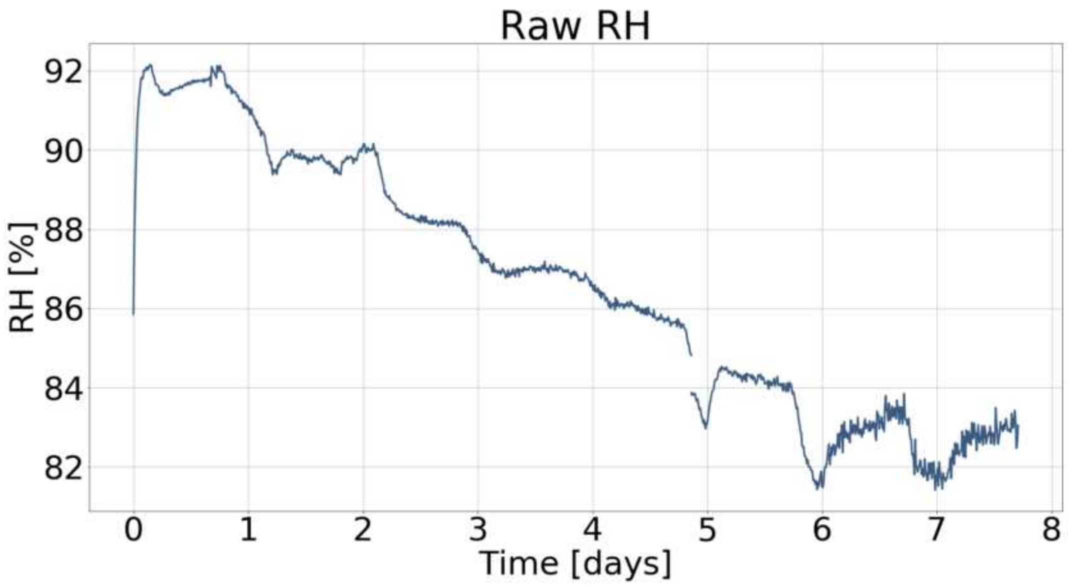


Figure 9: RH measurements of concrete using SHUTE sensor. The measurements have not been compensated for variations in temperature.

Conclusion

This whitepaper demonstrates that the SHUTE humidity sensor is reproducible and that the measurements are repeatable, even after submersion in water for 14 days. As an application example, the SHUTE sensor is used to monitor the drying of concrete for a period of 9 days. The measurments from the SHUTE sensor are compared to the measurements from a Vaisala HM40 humidity sensor.