

NDT for microstructure and moisture investigation of porous building material

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Abstract

Non-destructive testing methods are mostly applied and established for the detection of embedded mounting parts or structural defects in building elements. The assessment of the concrete microstructure or microstructural changes like chemical alterations or the formation of microcracks, e.g. due to material aging, freeze-thaw cycles, alkali-silica reaction and ettringite, is not in the focus of ndt research though. Concrete moisture and enhanced salt contents, which usually trigger all chemical microstructural changes, are other material properties, lacking reliable ways of measuring. But, the assessment of such material properties, on the long term also in a depth resolved manner, is definitely important, when the sustainability of our concrete infrastructure buildings shall be evaluated.

New consideration like the potential use of ndt, in particular the combination of different methods and alternate ways of data analysis are subject of research currently undertaken at BAM. These approaches involve for example working towards (i) a deeper understanding of how to measure moisture distributions reliably and follow transport phenomena, (ii) the use of stray phenomena in radar and ultrasound to locate material inhomogeneities or (iii) the application of LIBS for the delineation of diffusion and migration processes but also (iv) the use of new tools for data analysis like data fusion. First results are presented and new ideas discussed.

Keywords: microstructure, moisture, radar, monitoring, concrete deterioration, cracking, screed

1. Introduction

Investigating microstructural properties and chemical or physical states of building material (and concrete in particular) is an emerging research field at BAM. As this subject is so diverse and new it is actually too broad to be presented here in a comprehensive manner. Instead as only one example of what is being researched a recent experiment concerning comparative screed moisture measurements will be outlined. Especially floorers often run into the difficulty of having no tool to determine the moisture (or drying) state of screeds quantitatively, which is critical in order to prevent structural damage of floor covers. The non-destructive investigation of moisture and salt present in building material is generally still difficult. For this experiment a group of five research and industry partners worked together trying to evaluate the pros and cons of various moisture testing methods, comparing their potential and working towards new ways of data analysis. The experiment and some of our findings are described below.

2. Multimodal ndt approach to measure screed moisture

Measuring the moisture content of floor screeds is usually done at the construction sites with minor destructive testing methods like Darr drying or the Calcium Carbide (CM) method [1]. These require small samples, deliver only punctual information and still have proven not to be very reliable. Hence, a study has been made using these standard tests as well as a suite of non-destructive testing methods working out their use for moisture determination.

For the experiment a series of respectively six 35 mm and 70 mm thick cement and calcium sulphate based screed samples were prepared (giving a total of 24 samples) and stored for several months in a climatic chamber at 50% relative humidity and a temperature of 20°C (Fig. 1 left). Below the screed samples an actual floor construction consisting of impact sound

reduction and thermal insulation layers resting on washed-out concrete has been replicated. During drying and hardening of the samples all measurements were applied on a regular basis. At the end of the test all samples were Darr dried until weight stability.

In Fig. 1 (right) shows the results of the Darr and CM tests, which were carried out throughout the experiment. Generally the samples were taken with a drill hammer across the full cross-section and weighed between 100 and 200 g. The overall performance of the tests on the cement based (“CT”) samples was poor and not even a clear trend could be seen. For the anhydrite based samples (“CA”) the correlation to the real moisture values is much better. Since the handling and analysis was the same for all samples the observed discrepancy was evaluated as an indication that even the destructive “standard” methods have weaknesses and results must be treated carefully.

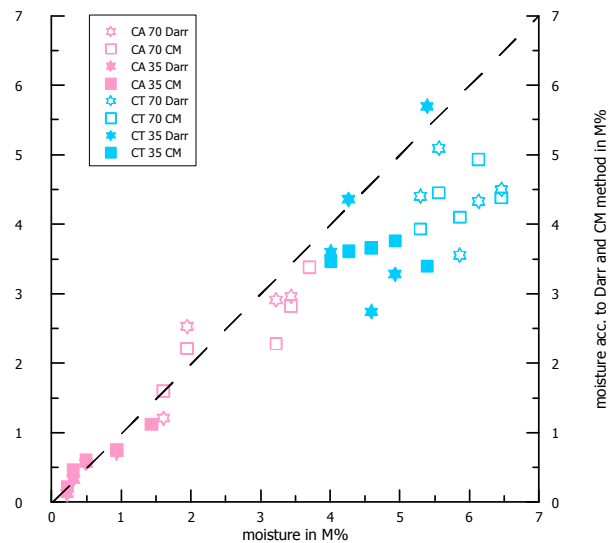


Figure 1. Photo of the samples in the climate chamber at $T = 23^{\circ}\text{C}$, $rH = 50\%$ (left). Results of the destructive Darr and CM methods measuring screed moisture. CA indicates anhydrite based screed and CT cement based screed (right).

At BAM an extensive ndt multi-sensor approach based on different physical principles has been used. The following methods were deployed:

- Ground Penetrating Radar (GPR) (SIR 3000 with 2.0 und 2.6 GHz antennas from *GSSI*)
- Microwave (sensor types Moist R1, R2, DM, PM from *Hf-Sensor*)
- Capacitive moisture probes (hydromette type Compact B from *Gann*, and G814 from *Denzel*)
- Electrics (4-point measurements with Wenner probe from *Proceq*)
- Ultrasound (50 kHz trans wave probe A1220 from *Acsys*)

For the principles of the methods the reader is referred to the respective literature [2, 3, 4]. Most of the applied methods showed clear dependencies on the changing moisture content that was often more prominent in the higher moisture ranges. Only the velocity change of the ultrasound trans waves was not significant or clearly related to moisture. Most promising in the low moisture range (below 3-4 M%) were electromagnetic and capacitive techniques. In the following a few selected observations will be presented, further information is also shown in [5].

3. Results

Figure 2 illustrates a comparison of the measurement results obtained with the hydromette, GPR and the two microwave sensors on the 35 mm thick cement based screed samples. The data are plotted against the average group moisture and the error bars depict the standard deviation between the six group members. The display value of the hydromette was converted into mass percent moisture based on the conversion table provided by the manufacturer. Whereas the results show a good correlation at high moisture contents the informative value of the hydromette decreases significantly below 3 M% as the display values remain too high. For the microwave sensors the so called moisture index minimum (FI minimum) was evaluated showing a strong dependence on the water content. Depending on the penetration depth (R1: 2-3 cm, R2: 5-6 cm) they see different drying behavior of the sample. The amplitude of the direct wave in GPR seems to be similar in sensitivity like the microwave sensor R2.

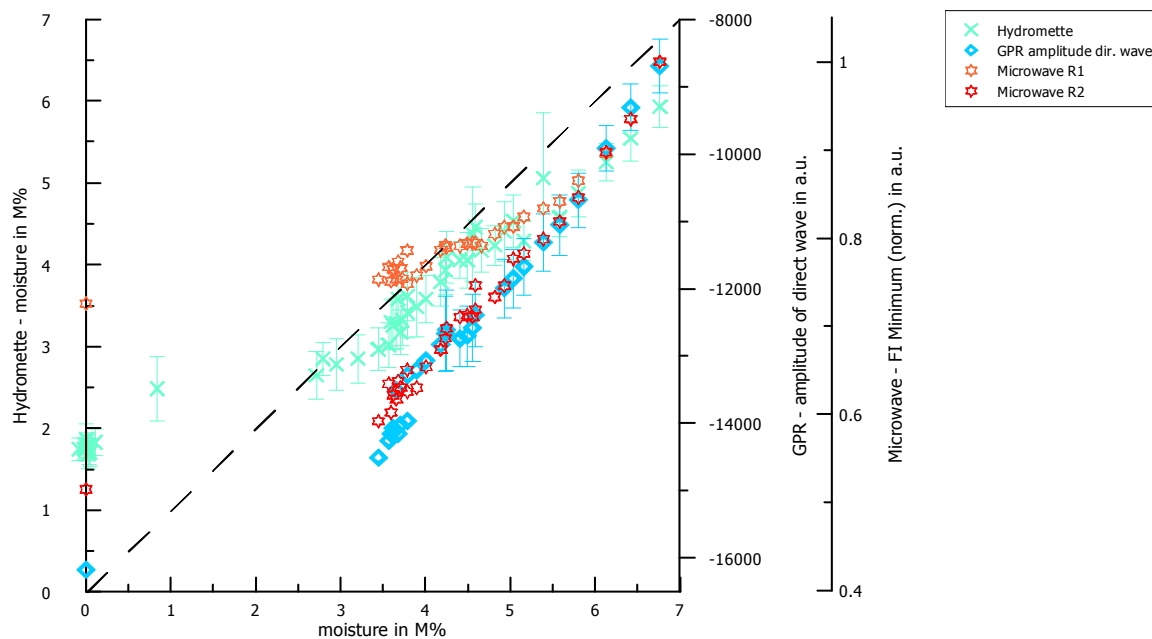


Figure 2: Comparison of the information contents of hydromette, GPR (amplitude of direct wave) and microwave sensors type Moist R1 and R2 as obtained on the 35 mm thick cement based screed samples.

Moreover the two affects of ongoing hydration and changing water contents were tried to delineate from each other through a subsequent “resaturation“ experiment. In order to measure the effect of changing moisture isolated from the affect of the hydration, the samples were re-saturated in a desiccator with tap water after the Darr drying. The experiment was realized in the frame of a BSc-thesis [6]. Some of the findings shall be illustrated using the example of GPR. Figure 2 shows the comparison of GPR amplitude data (direct wave and backwall reflection) obtained in the hydration (“hydr.”) experiment and in the subsequent saturation (“sat.”) experiment.

Whereas for the amplitudes of the direct wave no significant change was observed, the amplitudes of the backwall reflection show an offset at high moisture contents and converge at about 5 M%. It seems probable that the offset is caused by the hydration process and the thereby changing permittivity. The travel time difference between direct and reflected waves

yields information about the entire cross-section of the sample, but seemingly is not influenced by the hydration process. It may be followed that this is a promising parameter for moisture monitoring concerns.

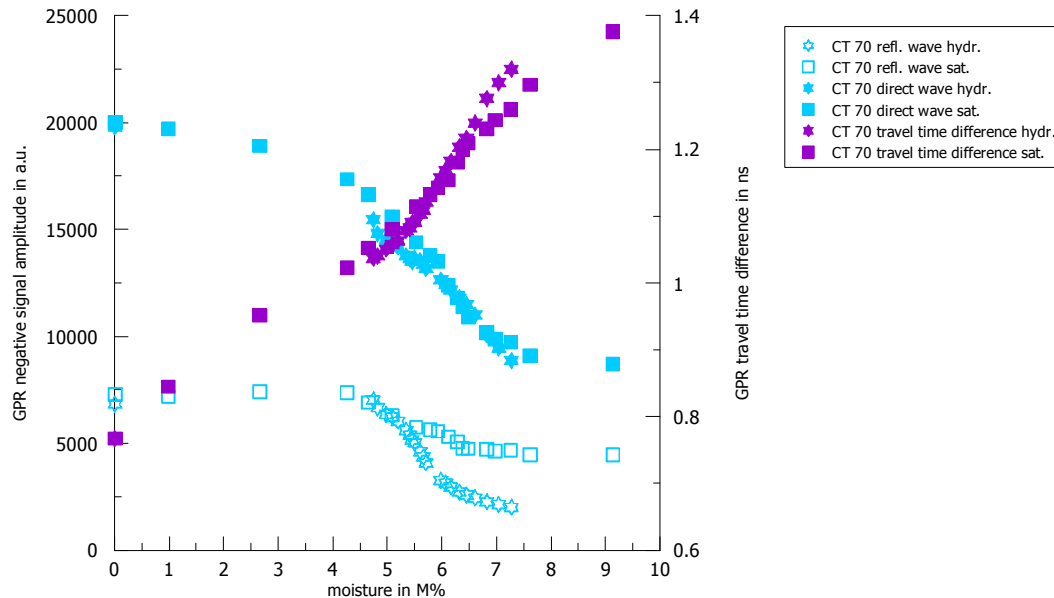


Figure 3: GPR, amplitudes of direct and reflected waves as well as travel time difference between the two during the hydration and the saturation experiment. Data measured with a 2.0 GHz antenna.

4. Conclusions and Outlook

Currently at BAM the potential benefit of ndt methods to address microstructural changes and moisture content as well as transport phenomena is intensively researched. Some of the ongoing work has been presented reporting on a comparison of different methods for cement and anhydrite based screed moisture testing outlining the promising parameters and their sensitivity in different moisture ranges. In a joint experiment with other research and industry partners the performance of the classical destructive moisture testing methods (Darr and CM) were compared with the results obtained with ndt techniques. Especially for low moisture contents (when the screed is dry enough to be covered with the final floor finish), several commercial devices including the most commonly used CM and Darr methods failed to determine the correct moisture content for cementitious samples. Capacitive and electromagnetic methods were the most sensitive ones in the test. It could also be shown that the hydration state influences the measured quantities and needs to be regarded.

In case of GPR the travel time difference between direct and at the backside reflected wave proved as the most reliable parameter – and seemed to be quite independent of the hydration state. It is clear though that this quantity also depends on the sample thickness (which is unknown and not a constant for real screeds). At the current state this parameter can only be used for relative information over time (as a monitoring tool) – but non-destructively be applied on large areas with little expenditure of time.

Future approaches will include the use of relative humidity sensors (wired and wireless as lost sensors) and multiring-electrodes in order to yield information on the vertical moisture gradients and study also moisture transport phenomena. The findings will closely be compared to moisture transport simulation studies.

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