

Continuous measurement of moisture content in building materials with Time-Domain Reflectometry

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Abstract

Measuring moisture content in building materials is essential both for professional practice as well as for research. However, this is a very complex task, especially when in-depth long-term minor destructive measurements are desired. The Time-Domain Reflectometry (TDR) technique can be a solution to fulfil these requirements, but its application in construction materials is still a great challenge, particularly for hard and low porous building materials. In this paper, a methodology to evaluate moisture content with TDR in consolidated materials is presented. In addition, the procedure was applied to a limestone sample to assess its moisture content during a drying experiment. The obtained results suggest that TDR is suitable for moisture monitoring in limestone, encouraging future applications and further developments.

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Keywords: Moisture content, Moisture monitoring, TDR, Building materials, Limestone

Nomenclature

ϵ_{app}	Apparent relative dielectric permittivity [-]
W	Moisture content [kg/m ³]

1. Introduction

There is a wide variety of techniques available for moisture content determination. However, many are only capable of providing surface moisture content measurements. In opposition, others require material sampling, and as a consequence successive measurements cannot be repeated at the same point. Furthermore, there are also methods that can only be employed in the laboratory and are not suitable to be used on-site, due to the requirements of the equipment involved, as happens with the nuclear magnetic resonance method (NMR) or with the radiation attenuation techniques, such as X-ray, neutron absorption, and γ -ray attenuation method [1]. The TDR technique can be seen as a solution to overcome these limitations but, despite its wide use for soil moisture measurements, its application in construction materials remains a challenge. The major obstacles to its current use in building materials are: (1) the difficulty of ensuring good contact between the TDR probes and the material; (2) the lack of appropriate calibration functions between the measured apparent relative dielectric permittivity (ϵ_{app}), and the moisture content of building materials (W); (3) the absence of standardized procedures to obtain the calibration functions; and (4) the need to develop tools for processing the electromagnetic signal.

2. Methodology

Figure 1 shows a step-by-step proposal to accurately assess moisture content with TDR in consolidated building materials. At the same time, it summarises how the aforementioned difficulties were solved. The first step involves performing an individual calibration of each TDR probe used, by making measurements in mediums with well-known relative permittivity (e.g. air and distilled water). The importance of this process to ensure accurate measurements, as well as all the details regarding its execution, is presented in [2]. The installation of the TDR probes in the study material is the following crucial step. The TDR probes used in this work were specially designed for application in hard building materials, and, as a consequence, they differ from commercial sensors conceived for soils, since they have thicker and more robust rods. In addition to the adoption of appropriate sensors, a steel auxiliary guide was developed to ensure good contact between the TDR waveguides and the material. After installing the probes, a set of graphics (called reflectograms) can be obtained for the different time instants under analysis (step 3). The processing of these direct outputs allows the relative dielectric permittivity, ϵ_{app} , of the material under study to be calculated (step 4). In one of the final and most important steps of this process, a calibration curve must be used in order to deduce the moisture content of the material from the measured ϵ_{app} values (step 5). Many authors have already shown that the empirical conversion functions developed for soil moisture measurements are mostly not suitable for building materials [3]. In addition, in the current state of research, general formulas based on dielectric mixing models are not yet available for distinct classes of materials [4]. Therefore, in this work, the calibration was done for the particular material under study using the gravimetric method as a reference. Finally, to quantify the evolution of moisture content over time, the development of automatic tools for rapid data processing is still required (step 6).

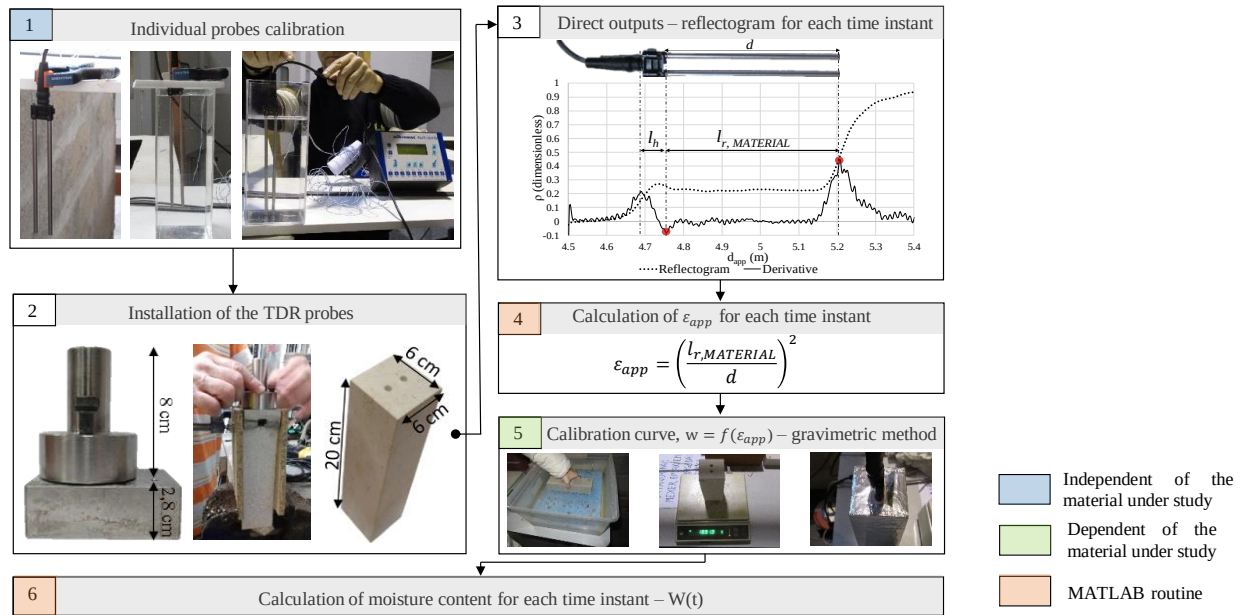


Figure 1. Proposed methodology for moisture content evaluation in building materials with the TDR technique.

3. Results and discussion

Figure 2 shows the results obtained on a limestone sample (20 cm x 6 cm x 6 cm) during a drying experiment performed at ambient temperature ($T_{\text{average}}=21.5^{\circ}\text{C}$ and $RH_{\text{average}}=53.8\%$), after applying the methodology proposed in Figure 1. The experiment started with the sample completely saturated and a continuous recording of TDR measurements was made until it dried. In Figure 2 (a) the reflectograms acquired at different time instants during the test are presented (step 3 of Figure 1).

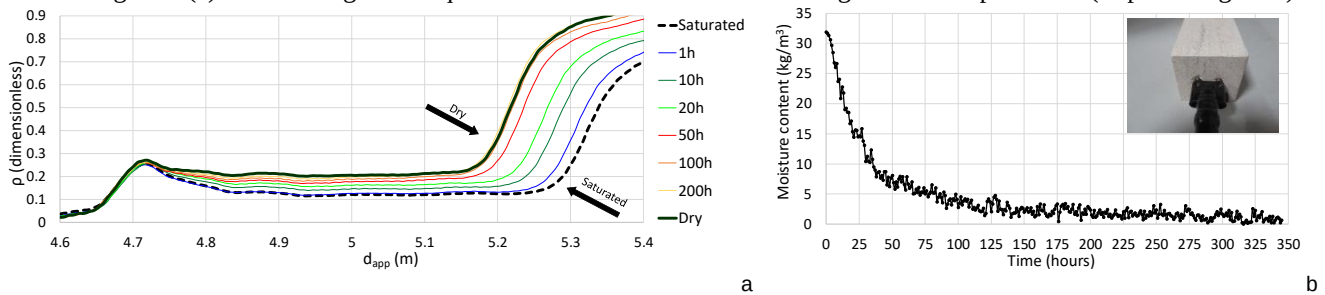


Figure 2. Results obtained during the drying experiment of a limestone sample: (a) reflectograms measured during the drying test; (b) evolution of the moisture content, $w(\text{kg/m}^3)$, during the drying period.

The results reveal a clear difference between the reflectogram collected when the sample was completely saturated and dry, as well as a gradual progression during the drying process which is consistent with what was expected. This type of result can be obtained without great effort in signal processing and without the time-consuming calibration process. However, it only allows a qualitative evaluation of the moisture content in the material, which may be enough for many practical civil engineering applications, such as the correct diagnosis of buildings' pathologies or the efficiency evaluation of the treatment solutions applied. In turn, it is possible to quantitatively measure the moisture content over time by following all the steps of the developed methodology, as can be seen in Figure 2 (b). This contribution is important to help in the accurate determination of some material properties or to validate on-site and laboratory models.

4. Conclusions

Monitoring moisture content in building materials is a complex subject, which is still the focus of ongoing research. Despite the wide use of the TDR technique, especially for moisture content measurements in soils, its application in construction materials still faces many challenges. The developed methodology (Figure 1) seems to solve the major obstacles to its current application in building materials, enabling successful moisture measurements in hard and low-porous materials (Figure 2). The results obtained are encouraging for further tests on full-scale walls, as well as future experiments on different building materials, capable of leading to a more widespread use of the technique.

References

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