Moisture Probe Calibration for Open Air Measurements in Rock Dwellings Locality in Brhlovce

[1]V Boháč, [1]D. Fidríková, [1]V. Vretenár, [2]T. Durmeková, [2]I. Šimková, [2]L. Petrýdesová, [2]J. Vlčko

[1]Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia
[2]Department of Engineering Geology, Faculty of Natural Sciences, Comenius University, Bratislava, Slovakia
Email: bohac@savba.sk

Abstract. *The aim of this paper is to show the calibration method of humidity sensors based on hot ball probes. The sensors are used for the monitoring of weathering and the damage of rock dwellings in Brhlovce village (Slovakia). The standard arrangement of hot ball probe is used for measuring thermal conductivity. The thermal conductivity of porous structure is dependent on moisture content in pores, so when pores are filled by air/vapor, water or ice the value of thermal conductivity is increasing. Moisture regime of moisture probes was studied in laboratory condition in order to find the range of thermal conductivity in dry and water saturated states in dependence on temperature. In situ monitoring of the temperature-moisture regime of volcanoclastic rocks has been running for one year.*

Keywords: Thermal Conductivity, Moisture Probe, Humidity Measurement in Porous Stones

1. Introduction

Porous materials – rocks situated in natural conditions are exposed to the sun radiation, precipitation, evaporation, freezing and thawing phenomena. Moisture in the rock walls under different climate conditions, e.g. the freeze and thaw processes at the abrupt temperature changes have destructive impact on stone durability. It is caused by cycles of drying – wetting and freezing – thawing processes. The resulting thermal conductivity of a porous material is a function of temperature and the water content of pores. In order to understand the weathering processes of rock dwellings the moisture regime is monitored by a moisture sensor in connection with RTM electronic unit (fy. TransientMS) constructed for long time monitoring of moisture under the open air conditions. The monitored parameters, e.g. moisture and temperature correlate with amount of rainfall and air temperature.

2. Physical background and principle of Hot-ball method

The investigation of the heat transport properties of materials in stationary and transient (dynamic) regime has been published in several papers [1], [2], [3], [4]. The stationary methods usually operate with gradient temperature over the thickness of specimen and thus it takes reasonable time to get stable or stationary state. This causes moisture redistribution in material bulk and changes of original moisture condition. In the case of transient methods it is used small temperature disturbance, which will take shorter time and causes no or minimal redistribution of moisture and thus the original thermodynamic state is preserved.

In-situ monitoring of moisture content in tuff massive is performed by small apparatus based on the transient hot-ball method on Fig. 1. The measuring procedure consists of the measurement of initially stabilized temperature (base line), switching on the step-wise heating pulse that generates heat flow and simultaneously scanning the temperature response. Model of the hot ball method [5] assumes a constant heat flux q from the empty sphere of radius r_b into the infinitive medium that starts to be generated for times $t > 0$ (Fig. 1 bottom). The long-time approximation of temperature function of the model is derived as the working relation of the measuring method [2]:

$$\lambda = \frac{q}{4\pi r_b T_m (t \to \infty)} \tag{1}$$

where λ is thermal conductivity of the surrounding medium and T_m is stabilized value of the temperature response reached in the long time limit. The measured temperature response is shown in Fig. 1 bottom. The maximum of temperature response is used to calculate the value of q/T_m that is adequate to the thermal conductivity and thus moisture content according a type of calibration.

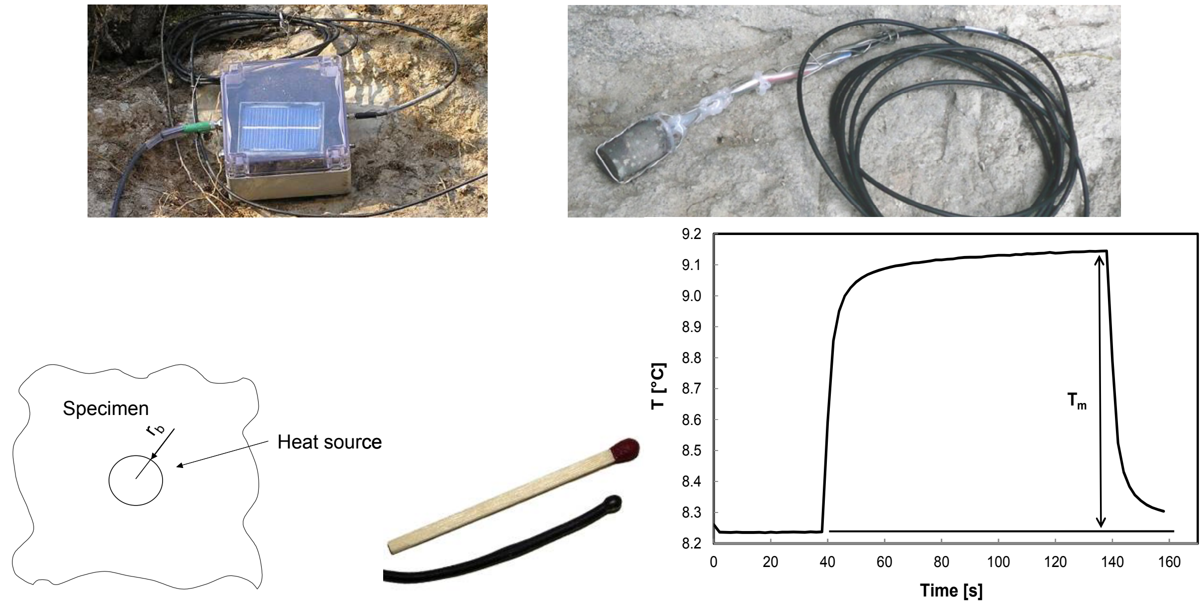

Fig. 1. RTM-electronic unit with solar panel for recharging (up left) and moisture sensor with wire connections (up right), model of the hot ball (down left) and probe real size picture (down middle). The example temperature response measured for tuff. Measurement takes 160s (100s heating) in the bottom right.

3. Experiment and calibration procedures

For the study there were selected the cores from drilling of holes for placing them back as the moisture sensors. The tuff cylinders from Brhlovce rock dwellings having diameter 32 mm were drilled in the middle. Hot ball probe having 2.5 mm in diameter was inserted into a center of such a hole in rock cylinder and cables were supported by cage made of nickel wires (Fig. 1 up right). Physical properties of tuff from Brhlovce locations varies and are the following: specific gravity 1.6÷2.6 $g.cm^{-3}$, volume density 0.909÷1.466 $g.cm^{-3}$, total porosity 31.2÷52.3 %, water absorption 16.4 % and uniaxial compression strength 17 MPa.

The moisture probes based on hot ball probe were calibrated in liquid media having different but known value of thermal conductivity. The water and glycerol were used as calibration points, so one can calculate thermal conductivity from measured values of q/T_m. Water and glycerol have the values of thermal conductivities in a range of thermal conductivity values of measured materials. Such a probe is inserted in a cylindrical core from drilling of holes and ready moisture sensor is at Fig. 1 (up right).

The measured value of heat flux and temperature maximum q/T_m inside the moisture sensor represents thermal conductivity that is dependent on moisture content (Fig. 2) in between dry and moisture saturated state. The difference of q/Tm represents 100% moisture scale in between dry and fully saturated content of pores by water. After saturation by water it was inserted in the tuff massif at Brhlovce and in-situ monitoring started in October 31st 2011. The values of thermal conductivity λ in the case of water saturated probes are much higher than the dried one (see Fig. 2). The calibrated moisture probe in Fig. 2 was inserted into a hole drilled in massive rock at locality of museum of rock dwellings in Brhlovce. The insertion depth of a moisture sensor is 10 cm. At the 23 °C it was monitored the moisturing process that is shown in Fig. 2. The high difference in the value of the q/Tm between dry and reached water-saturated state of tuff also proves its high water absorption.

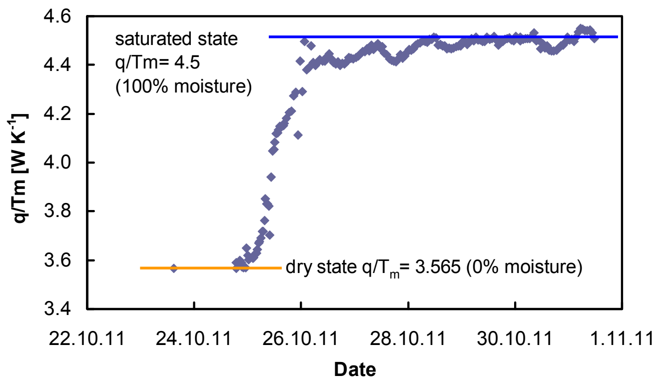

Fig. 2. Calibration of probe made of tuff stone in dry and moisture saturated state. Figure represents moisturing process at 23°C.

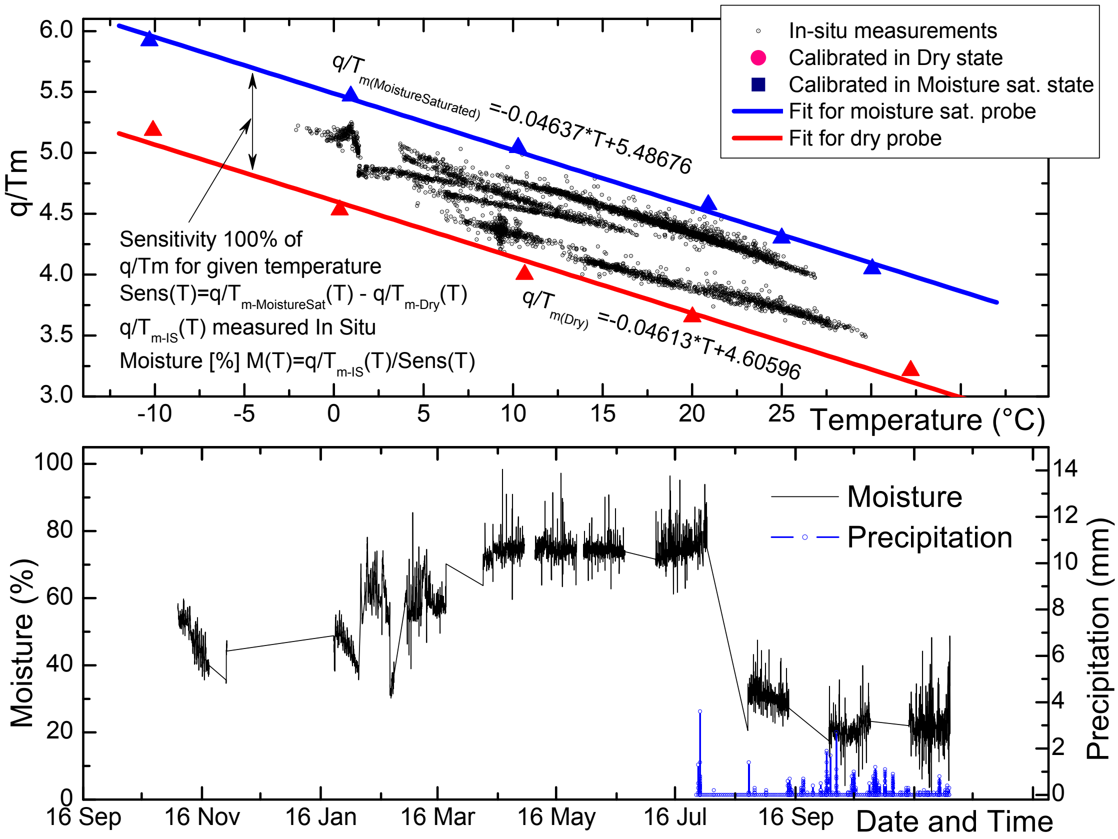

Fig. 3. Calibration lines of the temperature dependency of q/Tm values measured for tuff in dry and water saturated condition. The plot in blue and red are giving the sensitivity for difference in the moisture saturated and dry state and are compared with in-situ measured data in 10 cm of massif depth (Up). Calibration data were statistically averaged for a given temperature [6]. The same data from locality are plotted in time scale with precipitation data (down). The rain gauge station was installed in July 27th 2012.

The data from in-situ measurements were collected along one year and the values of q/T_m in dependency of temperature were plotted with calibration lines in Fig. 3. up. The moisture scale defined by calibration lines in q/T_m values were recalculated to the moisture content and plotted in a time scale in Fig.3. in the bottom. Changes represent a seasonal variation of moisture content. The water was evaporated in several steps so one can see several regions of data measured under similar moisture content. In a time the moisture was changed by very slow drying process. The lower values were measured in summer in August that was very dry with practically no rains and surface temperatures well above 30 °C.
For the next monitoring in depths at 30 and 50cm in tuff massive the new series of 10 probes were tested for the sensitivity. Moisture sensors in dry and moisture saturated state were calibrated in dependence of temperature. Linear dependency was found for different moisture content, so values of q/T_m can be recalculated to thermal conductivity or to moisture content directly from this calibration. The dry-moisture calibration was performed in laboratory conditions for the range of temperatures from -20 up to 22 °C like in Fig. 3.

4. Conclusions

Paper presents data on moisture change in dependency of temperature. Calibration methodology was elaborated and performed in climatic chamber and checked by TROTEC 600 during in situ monitoring of massif at locality in Brhlovce. For all of specimens, e.g. moisture sensors the dependency on humidity content variation with q/T_m parameter was found in dependency on temperature variations. Based on observed physical properties such as porosity, water absorption and thermal conductivity of studied materials; it was shown relationship between water absorption and increases of thermal conductivity.

Acknowledgements

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-0641-10, Study of rocks properties and investigation of structural and textural characteristic in correlation with thermophysical and physico-mechanical properties.

References

[1] Maglić, K.D., Cezairliyan, A. & Peletsky, V.E. (eds.) 1992. Compendium of thermophysical property measurement methods. Volume 2: Recommended measurement techniques and practices, Plenum Press, New York, p. 643.

[2] Kubičár, Ľ., Vretenár, V., Štofanik & V. Boháč, V. 2010. Hot-Ball Method for Measuring Thermal Conductivity, International Journal of Thermophysics, 31, 10, p. 1904-1918.

[3] Kubičár, Ľ. & Boháč, V. 1999. Review of several dynamic methods of measuring thermophysical parameters. In: Gaal, P.S. - Apostolescu, D.E. (eds.): Proc. 24th Int. Thermal Cond./12 Int. Thermal Expansion Symp., Technomic Pub. Co., Pittsburgh, Pennsylvania, p. 135-149.

[4] Krempaský J. 1969. The measurements of the thermophysical Properties, SAV, Bratislava.

[5] Carslaw, H.S. & Jaeger, J.C. 1986. Conduction of heat in solids, Oxford, Clarendon Press, Second edition, p. 348.

[6] Ekkertová, P., Šimková, I., Brček, M., Durmeková, T. & Boháč, V. 2012. Influences of temperature change and moisture content on the thermal conductivity of rocks. Proc. Thermophysics 2012, Podkylava, Slovak Republic, printed by: Brno University of Technology, Faculty of Chemistry, ISBN: 978-80-214-4599-4, p.33-40.