# Experimental Performance of Hygro-Thermal Deformation of Contemporary and Historical Ceramic Bricks

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*Abstract* — This paper presents an experimental study on moisture and temperature-induced expansion of contemporary and historical bricks. Moisture expansion coefficient is determined in the moisture range from dry material to 95 % RH at temperatures 20°C and 60°C. Thermal expansion coefficient is measured in temperature range from 20°C to 60°C at moisture 0 and 35 % RH. Temperature and moisture induced length differences were measured using LVDT MACRO SENSOR SBP 375040.

*Keywords* — moisture induced deformation, thermal deformation, moisture, brick.

## I. INTRODUCTION

BUILDING porous materials and structures are subjected to a number of climate actions which causes creation of defects. Mechanisms responsible for typical defects as the cracking and spalling of these materials are associated with length and volume changes due to moisture content or temperature changes [1-3].

Deformation caused by moisture changes is called hygric in the range between 0 and 95 % RH, and hydric when the material is in contact with or immersed in water.

Variations of sorption moisture in the porous building materials result in strong fluid-skeleton interaction forces in the pore space, which produce moisture induced deformation. The effect of moisture sorption on elastic behavior of porous building materials is strong, especially in the lower moisture content range.

Thermal movement of atomic or molecular particles is the cause of thermal deformation.

Hygric expansion is often not taken into account in practical calculations, although higher content of moisture can lead to hygric stress in the same range as thermal stress [4].

## II. BASIC MATERIAL PARAMETERS

The tested samples were two types of contemporary bricks (BC1, BC2) and two types of historical bricks (BH1, BH2) manufactured in nineteenth century.

Mineral composition of the bricks was determined by chemical analysis.

Measuring the bulk density and open porosity were carried out in this manner: Each sample was dried to remove physically bounded water (over drying at 105 °C). After that the samples were placed into the desiccator with vacuum. The specimen was then kept under water for 24 h. The mass of each specimen (dry sample - $m_d$, water saturated sample – $m_s$, immersed water saturated sample $m_s$) was measured with 0.01 g accuracy. The volume $V$ of the sample was determined from the formula $V = \dfrac{m_s - m_d}{\rho_w}$, where $\rho_w$ is the water density. The open porosity $\psi_o$ was calculated according the formula $\Psi_o = \dfrac{m_s - m_d}{V \rho_w}$. The bulk density $\rho$ was calculated according the formula $\rho = \dfrac{m_d}{V}$.

The measurements of the sorption isotherms were determined using the climatic chamber. The climate maintains the desired temperature with the accuracy $\pm 0,4°C$ and relative humidity with the accuracy $\pm (0,2\% RH$ for low *RH* and $2\% RH$ for high *RH*). The weight changes were measured by milligram accuracy for a capacity up to 310 g.

## III. THERMAL AND MOISTURE EXPANSION PARAMETERS

Length changes of the specimen affected by the changes of temperature were valued by parameters thermal strain $\varepsilon_T$ [*mm/m*] and linear thermal expansion coefficient $\alpha_T [K^{-1}]$:

$$\varepsilon_T = \frac{\Delta l}{l_{0T}}, \qquad \alpha_T = \frac{1}{l_{0T}} \frac{\partial l_T}{\partial T} \qquad (1)$$

where $\Delta l = l_T - l_{0T}$, $l_{0T}$ is the length of a specimen at the reference temperature, $l_T$ - measured length of a specimen at the measured temperature.

Moisture-caused deformations of the specimen are valued by parameters moisture strain $\varepsilon_u$ [$mm/m$] and linear hygric expansion coefficient $\alpha_u[-(\%u)^{-1}]$:

$$\varepsilon_u = \frac{\Delta l}{l_{0u}}, \qquad \alpha_u = \frac{1}{l_{0u}}\frac{\partial l_u}{\partial u} \qquad (2)$$

where $\Delta l = l_u - l_{0u}$, $l_{0u}$ - basic length of a dry specimen, $l_u$ measured length of a moist specimen, moisture content is defined as $u = (m_m-m_d)/m_d$, where $m_m$ is mass of moisten material, $m_d$ is mass of dried material.

## IV. EXPERIMENTAL PROGRAM

Both, the moisture induced deformation and temperature induced deformation were measured in the equipment (Fig. 1 and Fig. 2 [5]) using the precise displacement measurement by LVTD sensor located into zerodur closed loop measurement frame which provides the resolution of the length changes $10^{-4}$ mm. Temperature and humidity of dilatometer chamber are regulated. Temperature range is from -15°C to 105°C with the accuracy $\pm 0,4°C$ and moisture range is from 10% to 95% relative air humidity with the accuracy $\pm(0,2\%RH$ for low *RH* and *2%RH* for high *RH)*. The sample holder is made from stainless steel. The measurement process is PC controlled.



1 – servo system, 2 – LVDT sensor, 3 – humidity and temperature sensors, 4 – sample, 5 – heating and moistering, 6 – fan, 7 – sample cell, 8 – measuring moveable rod
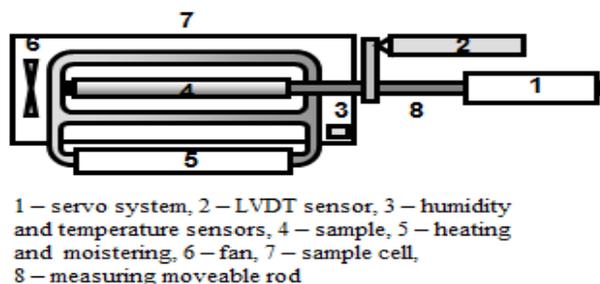
Fig. 1. Scheme of dilatometer.



Fig. 2. Dilatometer for measurement of temperature and moisture induced expansion.

Temperature deformation determining is performed in the dilatometer chamber environment at fixed relative humidity and at the different temperatures.

Moisture deformation determining is performed in the dilatometer chamber where the dry specimen is moistened gradually according to sorption process at constant temperature.

The measured sample is shaped as 1D rod (15cm x 1.5cm x 1.5cm). The process of moisture diffusion is an inert one, and therefore the experiments of investigation of deformations are time-consuming.

## V. RESULTS

The crystal phase identified in brick specimens are summarized in Table 1. As follows from the data, the tested bricks had practically identical mineral composition. Both the contemporary and the historical brick were manufactured in western part of Slovakia.

Basic material parameters of studied bricks are in Table 2. We can see that difference between bricks in open porosity is clearly related to the lower bulk density of brick with the greater pore volume.

However water vapor isotherm values of the historical samples (Fig. 2) were significantly higher than the contemporary samples (Fig 1). This discrepancy could result from their possible salt contamination. The chemical analysis in Table 3 for determination of chloride, sulphate and nitrate anions confirmed this assumption. The maximum total salt amount was in case BH2, that is very good agreement with correspondent isotherm values. However it is necessary to point out that the presented values are only approximate. Nevertheless it possible to note, that the estimated considerably higher total salt amount of BH2 is in good agreement with the significantly higher hygroscopic moisture content of this brick.

Table 1. Crystal phases in brick specimens.

| Brick | Identified phases |
|---|---|
| BC1 | Quartz, muscovite, feldspars, enstatite (Fe, Mg), hematite, illite |
| BC2 | Quartz, muscovite, feldspars, enstatite (Fe, Mg), hematite |
| BH1 | Quarz, muscovite, feldspars, calcite, hematite, illite |
| BH2 | Quartz, muscovite, feldspars, calcite, hematite, illite, montmorrilonite |

Table 2. Basic material parameters.

| Brick | Bulk density (kg m$^{-3}$) | Density (kg m$^{-3}$) | Total porosity (-) | Open porosity (-) |
|---|---|---|---|---|
| BC1 | 1370 | 2760 | 0.52 | 0.47 |
| BC2 | 1430 | 2790 | 0.47 | 0.40 |
| BH1 | 1790 | 2740 | 0.33 | 0.33 |
| BH2 | 1720 | 2700 | 0.35 | 0.31 |

Table 3. Identified concentration of salts in historical bricks.

| Brick | sulfides | | chlorides | | nitrides | |
|---|---|---|---|---|---|---|
|  | %w | mmol/kg | %w | mmol/kg | %w | mmol/kg |
| BH1 | 0.17 | 18 | 0.01 | 2 | 0.70 | 17 |
| BH2 | 0.37 | 37 | 0.07 | 20 | 0.60 | 96 |

In Fig. 3 and 4, there are shown the dependence of the strain

Fig. 3 and Fig. 4 show dependence of the strain of the two contemporary and two historical bricks on the moisture content at 20°C respectively 60°C. The functions $\varepsilon_u(u)$ are strongly nonlinear at low moisture values ($< 0,35$RH).

Linear hygric expansion coefficients $\alpha_u[mm/m]$ are shown in Fig. 5 and Fig. 6 at 20°C respectively 60°C.

Fig. 7 and Fig. 8 show dependence of the strain of BC1, BC2, BH1, BH2 bricks on the temperature at $u = 0$ respectively 35 %. The linear functions $\varepsilon_T(T)$ are quite sufficient to express the $\alpha_T$ from the range $5 - 6,1.10^{-6}K^{-1}$ for dry specimens and from the range $7,1 - 8,2.10^{-6}K^{-1}$ for moisture content 0,35 kg/kg. The linear thermal expansion coefficients $\alpha_T(T)$ were determined at drainage conditions (constant pore pressure, slow heating rate).

It is important to note that it is a fairly complex highly time-consuming task to make proper measurements of moisture expansion.
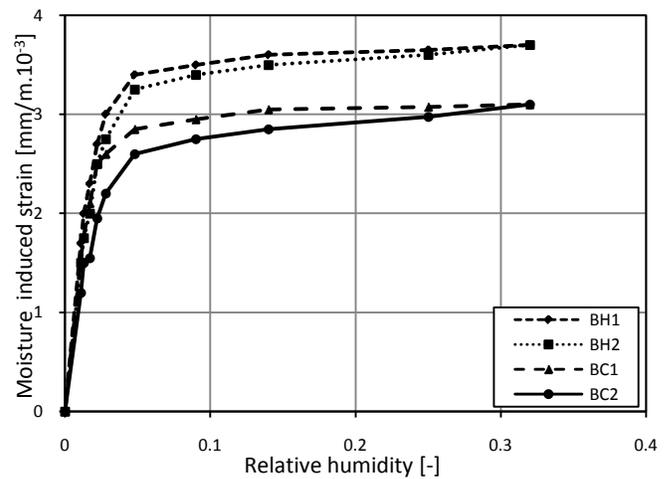


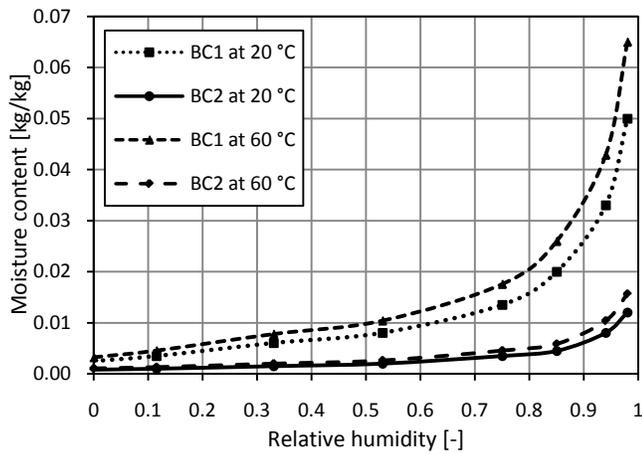Fig. 1. Water vapour isotherms of contemporary bricks BC1, BC2 at temperatures 20 °C and 60 °C.



Fig. 2. Water vapour isotherms of historical bricks BH1, BH2 at temperatures 20 °C and 60 °C.



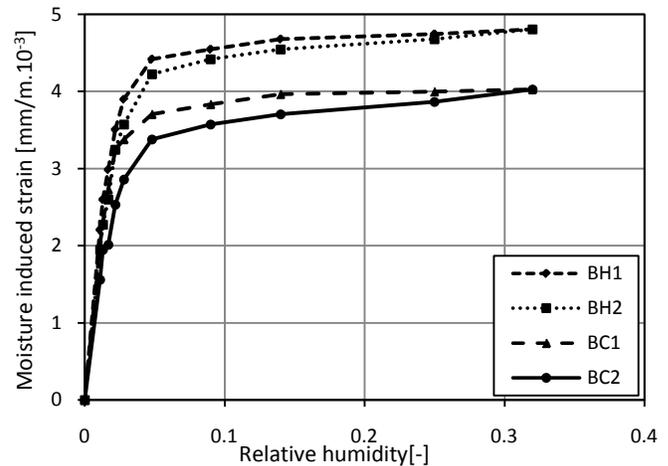Fig. 3. Moisture induced strain of historical bricks BH1, BH2 and contemporary bricks BC1, BC2 at temperature 20 °C.
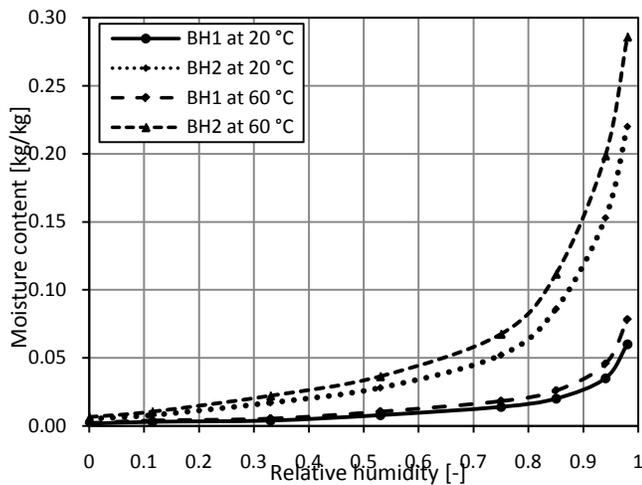


Fig. 4. Moisture induced strain of historical bricks BH1, BH2 and contemporary bricks BC1, BC2 at temperature 60 °C.
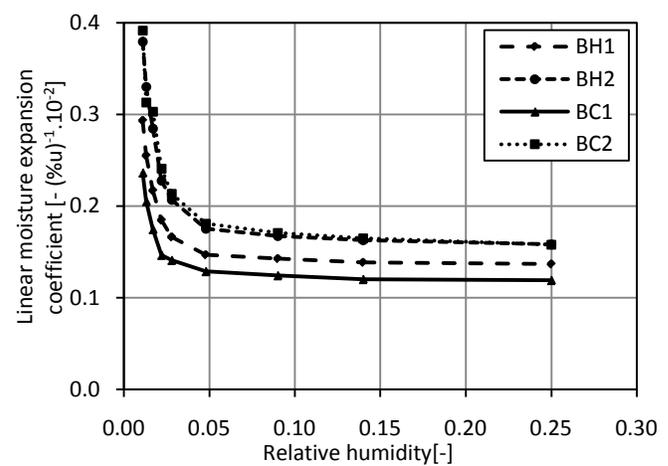


Fig. 5. Moisture induced expansion coefficient of historical bricks BH1,BH2 and contemporary bricks BC1, BC2 at 20 °C.
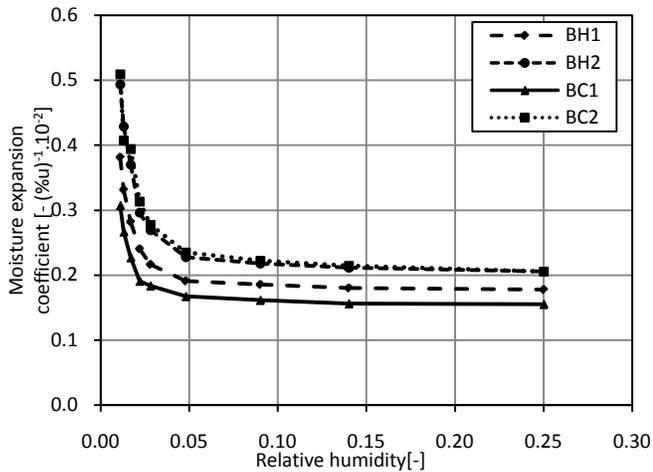
Fig. 6. Moisture induced expansion coefficient of historical bricks BH1,BH2 and contemporary bricks BC1, BC2 at 60 °C.
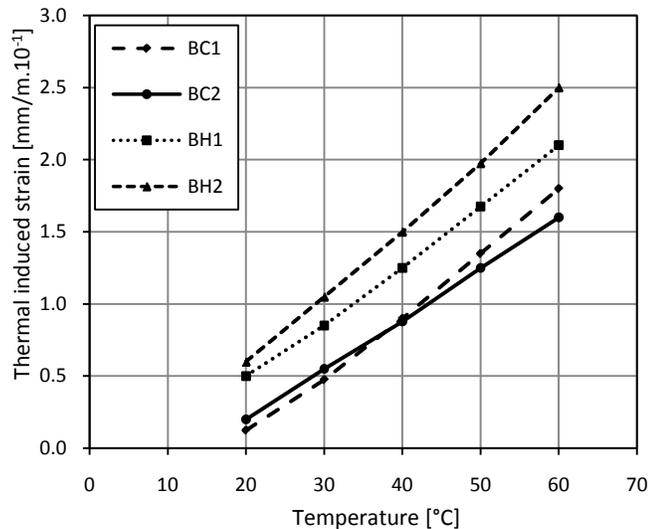


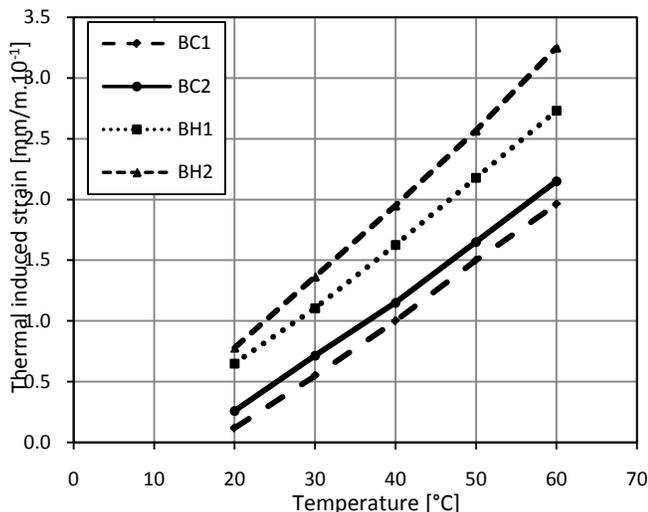Fig. 7. Thermal expansion of dry historical bricks BH1, BH2 and contemporary bricks BC1, BC2.



Fig. 8. Thermal expansion of historical bricks BH1, BH2 and contemporary bricks BC1, BC2 at relative humidity 35 %.

## VI. CONCLUSION

The linear thermal and moisture expansion coefficients were established in this study for four types of bricks.

To simulate and accurate make prediction the deformation of porous materials caused by the coupling effect of moisture and temperature mathematical modeling approach based on the mechanism of heat and moisture transfer is needed. Experimental value of the linear thermal and moisture expansion coefficients has to be used as basic input data of that mathematical model.

## VII. CONCLUSION

A conclusion section is not required. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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