An Experimental Determination of Coupled Thermal and Moisture Expansion of Plasters

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Abstract **- The objective of this paper is to evaluate, together with adsorption and desorption processes, moisture and temperature induced deformations of two plasters. The measurements are performed for moisture content from the dry state to the saturation water content and temperature range of 5 – 60°C. The coupled temperature and moisture induced length differences are measured using LVDT MACRO SENSOR SBP 375040.**

Index Terms**— Experimental measurement, plaster, moisture expansion, thermal expansion.**

I. Introduction

Mechanisms responsible for typical defects as the cracking and the spalling of facades are associated with length or volume changes of porous materials due to moisture content or to temperature changes [1-3]. These crucial properties of moisture and temperature induced deformation are often less appropriate regarding to the variable moisture content and temperature in the masonry which leads to low durability and short service life of surface layers. The choice of materials for surface layers should be estimated on the basis of knowledge of their thermal and moisture induced deformation behavior.

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

In this paper experimental determination of the dependences of moisture induced expansion of two commercial lime-based plasters upon moisture at temperatures 20°C and 60°C are presented. Thermal expansion was determined upon ambient relative humidity 40%.

II. Thermal and Moisture Expansion Parameters

Length changes of specimen affected by the changes of temperature are valued by parameter thermal strain $\varepsilon_T\,[mm/m]$:

$$\varepsilon_T = \frac{\Delta l}{l_{0T}}, \tag{1}$$

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 specimen are valued by parameter moisture strain $\varepsilon_u\,[mm/m]$:

$$\varepsilon_u = \frac{\Delta l}{l_{0u}}, \tag{2}$$

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 $u = (m_m\text{-}m_d)/m_d$, where m_m is mass of moisten material, m_d is mass of dried material.

III. 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, repeatability in the temperature range from -15°C to 105°C and from 10% to 95% relative air humidity. The sample holder is made from stainless steel. The measurement process is PC controlled.

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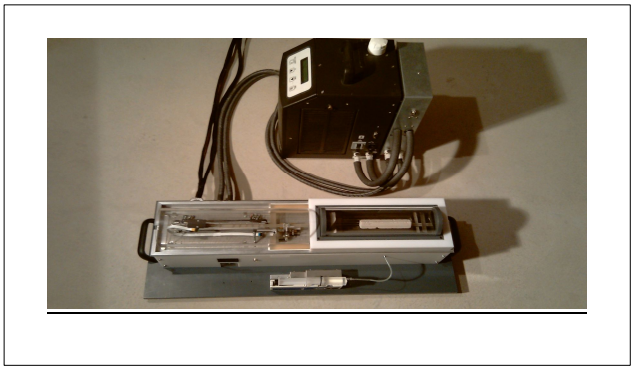

Fig. 1. Dilatometer for measurement of temperature and moisture induced expansion.

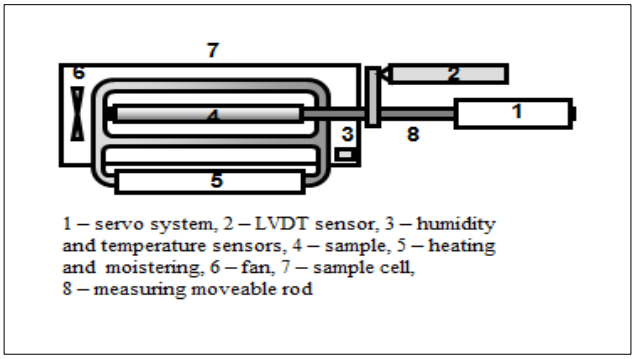

Fig. 2. Scheme of dilatometer.

The basic points of the experimental methods intended for the analysis of both, the temperature and moisture deformations are:

A/ the dry specimen is moistened gradually according to sorption process

B/ the dry specimen is moistened in the environment of fixed relative humidity at the different temperature.

The dry state is achieved at an ambient temperature $(103 \pm 2)°C$.

The measured sample is shaped as 1D rod (15cm x 2cm x 2cm). The process of moisture diffusion is an inert one, and therefore the experiments of investigation of deformations are time-consuming.

IV. Results

Basic material parameters of studied plasters are in the Table I and the pore distribution curves are in the Figure 3. We can see that difference between plasters in open porosity is clearly related to the lower bulk density of plaster with the greater pore volume.

TABLE I. Basic material characteristics of plasters

Sample name	*Bulk density [kg.m^{-3}]*	*Matrix density [kg.m^{-3}]*	*Open porosity [% m^{3}m^{-3}]*
Plaster 1	1410	2510	37.1
Plaster 2	1370	2490	44.7

The pore size distribution curves were measured by mercury intrusion porosimetry. The experiments were carried out using the instrument Poremaster 60GT.

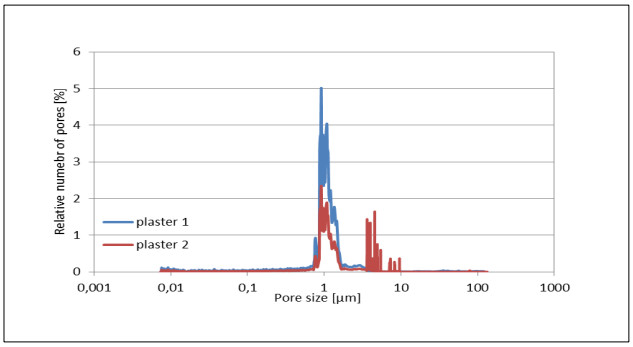

Fig. 3. Pore size distribution curves of plasters.

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.

In the Figure 3 we can see that the sorption and desorption isotherms of studied plasters are different, they correlate with basic material characteristic in Table 1 and with the pore size distribution curves at Fig. 3. The highest value of water sorption was achieved by the lightweight plaster 2.

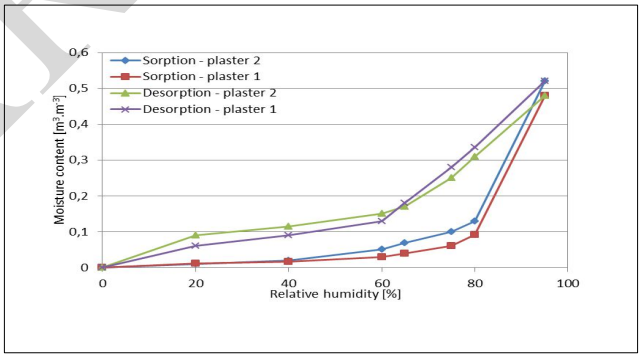

Fig. 4. Sorption and desorption isotherms of plasters at 60 °C.

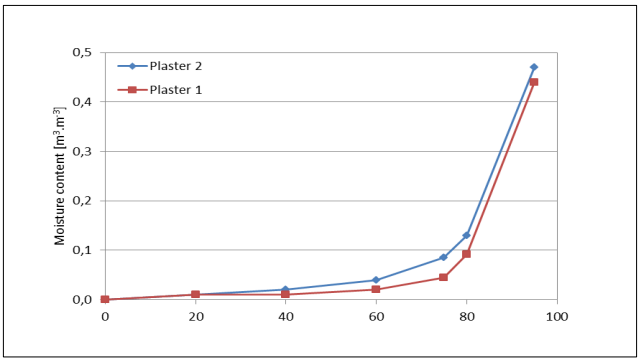

Fig. 5. Sorption isotherm of plasters at 20 °C.

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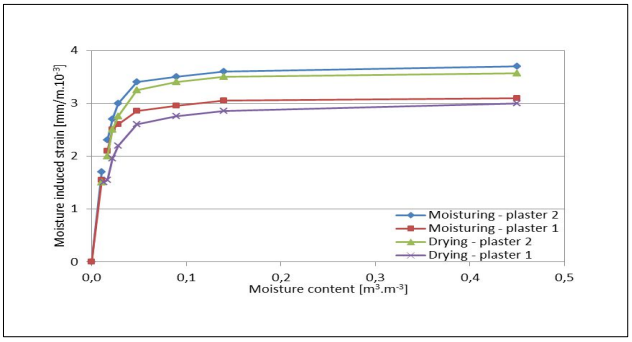

Fig. 6. Moisture induced strain at moisturing and drying of plasters.

Measured moisture induced strain values (Figure 6) demonstrate the very fast moisture strain grow with moisture content in the range of low moisture content values (< 10 – 15%) what is about 50%*RH* of environment, there is a rupture and moisture deformation rises slightly. From the value of 0.2 onwards there is no moisture deformation. We do not return to the dry state but only to value of 0.15 what is equivalent to 35%*RH* of air. This confirms that the presence of water significantly influences the elastic response in porous materials due to the activation of molecular forces and pore surface energy phenomena.

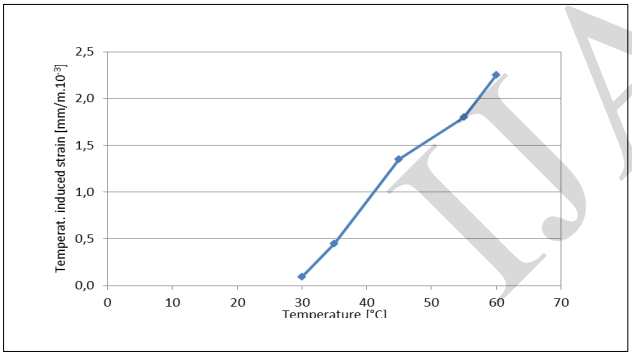

Fig. 7 presents the dependence of the thermal expansion of lime plasters on temperature upon 40%RH of environment. These measured values have the same order as values of moisture deformation. The coefficients of linear thermal expansion for plasters are from the range of $6.2 \times 10^{-6}\ K^{-1}$ to $15 \times 10^{-6}\ K^{-1}$ [6], which correspondent with our values.

Fig. 7. Moisture induced strain at moisturing and drying of plasters.

V. Conclusion

The moisture and temperature induced strain were established in this study for two plasters. The results of the experimental work done in this paper show that the moisture content has significant influence on deformation which might be induced in plasters due to moisture changes. The moisture deformations might be equal to or higher than the stress caused by temperature changes.

Coupled influence of temperature and moisture on expansion porous materials can provide useful information in the design of building structures which are exposed to the temperature and moisture changes.

Temperature and moisture induced strains belong to the fundamental entry parameters for mathematical models predicting deformation behavior of porous materials undergoing bound processes of heat, moisture and air transfer.

Although volume changes of porous materials are very important phenomenon observed in the macroscopic scale the understanding of causes points to the microscopic scale where fundamental explanation and relationship should sought.

Acknowledgment

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