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Coupled Thermal and Moisture Expansion of Porous Materials[1]

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A method for measuring the coupled influences of temperature and moisture on the linear thermal expansion of porous materials is proposed. The method is based on length measurements using a comparator and on application of the superposition principle to the relative elongation due to temperature and moisture changes. The application of the proposed method is illustrated on the heat-insulating building material Dekalit P. Measured results show a significant influence of the rate of moistening and drying as well as the moistening method itself on the linear expansion. The differences in the linear moisture expansion coefficient caused by these effects can achieve several hundreds percent. The thermal expansion behavior of Dekalit P is found to be regular, the linear thermal expansion coefficient being constant in the temperature range of −30 to 180°C. Generally, for Dekalit P, the influence of moisture on linear expansion is more important than the influence of temperature.

KEY WORDS: moisture; moisture expansion; porous materials; thermal expansion.

1. INTRODUCTION

The linear expansion of solid materials is measured by dilameters. Various techniques are used in this measurement, e.g., methods employing changes in the electric resistance, capacitance, inductance, interference optical methods, methods based on using the mirror and the scale, etc. In measuring the linear expansion of solid bar-shape materials, Abbe's comparator, The Edelmann's dilatometer, and a contact comparator (see Refs. 1–3 for details) are examples of the usual equipment. Small samples can be

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effectively measured by, e.g., Chevenard's [4, 5] dilatometer. Optical interference methods can be employed in the high- or low-temperature region. A typical representant of this kind of dilatometers is the Priest's dilatometer [5, 6].

The linear expansion is usually considered in the sense of the thermal expansion. However, the linear expansion caused by thermal effects is a good approximation only for homogeneous materials [7]. In heterogeneous systems this approximation may not always be valid due to the different mechanical and thermal properties of the components of the system. In the particular case of porous materials, the influence of moisture content must be taken into account [7].

In this paper, a method for measuring the coupled influences of temperature and moisture on the linear expansion of porous building materials is proposed.

2. METHOD FOR MEASURING THE COEFFICIENTS OF LINEAR THERMAL AND MOISTURE EXPANSION

The infinitesimal change of length due to the change of temperature is defined by

$$dl_{\mathrm{T}} = l_0 \alpha_{\mathrm{T}}\, dT \tag{1}$$

where l_0 is the length at the reference temperature T_0, and α_T is the linear thermal expansion coefficient. In an analogous way, the linear moisture expansion coefficient α_u can be defined,

$$dl_{\mathrm{u}} = l_0 \alpha_{\mathrm{u}}\, du \tag{2}$$

where

$$u = 100\,\frac{m_{\mathrm{m}} - m_{\mathrm{d}}}{m_{\mathrm{d}}} \tag{3}$$

is the moisture content (%), m_{m} the mass of the moistened material, and m_{d} the mass of the dried material.

Applying, in the first approximation, the superposition principle to the length changes due to temperature and moisture, we arrive at

$$dl = dl_{\mathrm{T}} + dl_{\mathrm{u}} = l_0(\alpha_{\mathrm{T}}\, dT + \alpha_{\mathrm{u}}\, du) \tag{4}$$

Defining the relative elongation ε as

$$\varepsilon = \frac{\Delta l}{l} = \frac{1}{l_0}\int_{l_1}^{l_2} dl \tag{5}$$

we obtain

$$\varepsilon(u, T) = \varepsilon_T(u_0, T) + \varepsilon_u(u, T_0) = \int_{T_0}^{T} \left(\frac{\partial \varepsilon}{\partial T}\right)_u dT + \int_{u_0}^{u} \left(\frac{\partial \varepsilon}{\partial u}\right)_T du$$

$$= \int_{T_0}^{T} \alpha_T \, dT + \int_{u_0}^{u} \alpha_u \, du \tag{6}$$

Measuring the linear moisture expansion coefficient α_u at a constant temperature with the varying moisture content is relatively easy. On the contrary, the determination of α_T for porous materials is a little more complicated, since it is technically difficult to keep the absolute moisture content constant when the temperature is changing.

Therefore, in practical measurements we first determine the dependence of the relative elongation on moisture at room temperature. The material is moistened either to the maximum moisture content or to the equilibrium moisture content, and then it is slowly dried with a simultaneous measurement of the length changes. Thus, a relation $\varepsilon_u = \varepsilon_u(u)$ is obtained over a wide range of moisture and at constant temperature. The function $\varepsilon_u(u)$ is represented by point values. Therefore, a regression analysis is necessary to obtain a continuous function. In accordance with Eq. (6), α_u is obtained as the first derivate of $\varepsilon_u(u)$. Knowing the function $\alpha_u(u)$, we can continue with the temperature changes. Considering the superposition principle, we first measure the length changes caused by the changing temperature and simultaneously determine the changes of moisture content. Then, these length changes are recalculated to the zero moisture content using the $\varepsilon(u)$ functions, which results in a pointwise given function $\varepsilon_T = \varepsilon_T(T)$ for a constant moisture $(u = 0)$ as required by Eq. (6). Regression analysis and calculation of the first derivate of $\varepsilon_T(T)$ with respect to T lead to the function $\alpha_T = \alpha_T(T)$.

3. APPLICATION

The application of the proposed method was illustrated on the samples of the heat-insulating material Dekalit P, which was developed as an environment-friendly substitute for asbestos cement, where the asbestos is replaced by cellulose (producer: EZA Šumperk, Czech Republic). The dimensions of the samples were 10 × 40 × 177 mm; the ends of the longest side were provided by the contact seats for use with the contact comparator.

In order to achieve the specified temperature and moisture content, samples were put into a Brabender conditioning chamber. After tempering, the mass of the samples was determined for calculating the moisture content, then again tempered for a while to assure precisely the chosen temperature. The changes of length were measured by a Carl Zeiss optical contact comparator with a precision of ±1 μm; the mass changes were determined by an electronic balance Sartorius. The basic set of points $l_i(m_i, T_i)$ was obtained in this way.

The subsequent measurements were performed in three phases. First, the samples were dried at a temperature of 160°C until a near-zero moisture content was achieved (we call this phase A–B below), and the values of moisture in the particular measurements calculated. Then the samples were moistened at a constant temperature of 22°C, and slowly dried, for a few minutes also at a temperature of 110°C (C–D phase). In the third phase, the samples were dried and then moistened under the same conditions (E–F phase). Simultaneous measurements of the length and moisture were performed as well.

Drawing on the history of the length of the samples, the three mentioned phases, A–B, C–D, and E–F, can be clearly distinguished, as illustrated in Fig. 1 for a typical sample. It is easy to recognize in Fig. 1 that the linear moisture expansion coefficient α_u will differ significantly in these three phases of moistening and drying.

The calculated values of the relative elongation dependent on the moisture content in the three mentioned phases are summarized for three typical samples in Figs. 2–4. The solid lines in these figures are the results of a regression of the experimental data. A linear relation was quite sufficient to express the $\varepsilon(u)$ function here, which means, regarding Eq. (6), constant linear moisture expansion coefficients in all three phases. In the

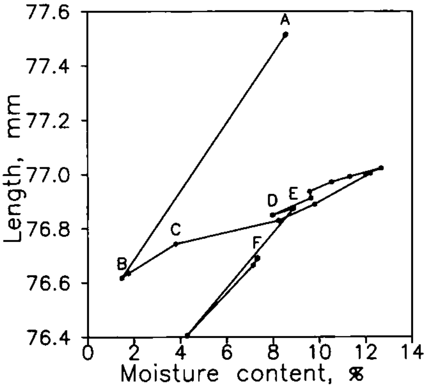

Fig. 1. The length changes of Dekalit P during the moistening and drying processes.

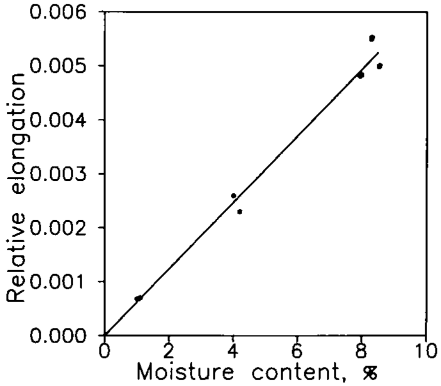

Fig. 2. The dependence of the relative elongation of Dekalit P on the moisture content for the constant temperature of 22°C during the first phase, which corresponds to the A–B line in Fig. 1.

first phase, we calculated $\alpha_u = 6.18 \times 10^{-4}$ $(\% u)^{-1}$; in the second phase, $\alpha_u = 1.67 \times 10^{-4}$ $(\% u)^{-1}$; and in the third phase, $\alpha_u = 5.79 \times 10^{-4}$ $(\% u)^{-1}$. These differences can be explained by the structural changes of Dekalit P in the temperature range 100 to 200°C (the material contains cellulose).

Using the measured values of α_u, the length changes in the first set of measurements were recalculated to the zero moisture content. In Fig. 5, the

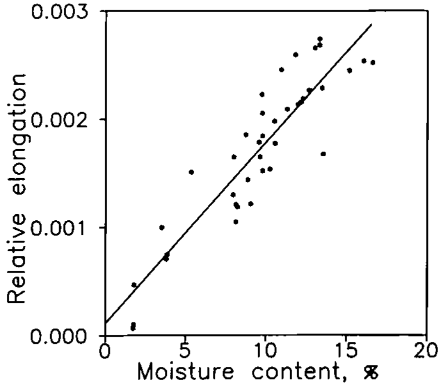

Fig. 3. The dependence of the relative elongation of Dekalit P on the moisture content for the constant temperature of 22°C during the second phase, which corresponds to the C–D line in Fig. 1.

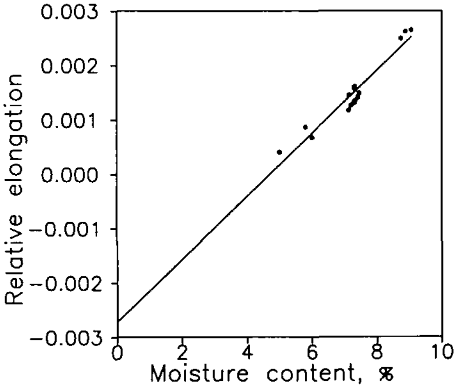

Fig. 4. The dependence of the relative elongation of Dekalit P on the moisture content for the constant temperature of 22°C during the third phase, which corresponds to the C–D line in Fig. 1.

dependence of the relative elongation on temperature with $u = 0$ is shown. Also, here, a linear function $\varepsilon(u)$ was a good approximation to the measured data, giving in the temperature region of −30 to 180°C, a value of the linear thermal expansion coefficient $\alpha_T = 1.345 \times 10^{-5}\ K^{-1}$.

4. CONCLUSION

The method for determination of the coupled influences of temperature and moisture on the linear expansion of porous materials

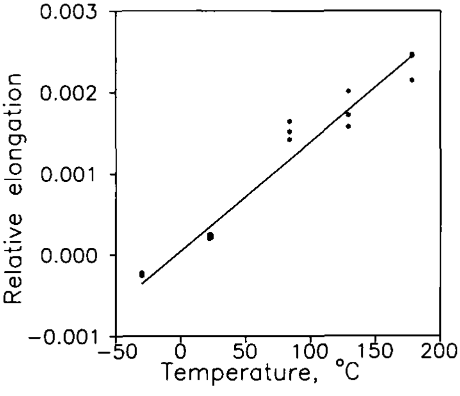

Fig. 5. The dependence of the relative elongation of Dekalit P on temperature for $u = 0$.

proposed in this paper is very easy to use and can provide useful information, for example, in the design of building structures which face temperature and moisture changes. Application of the method to typical heat-insulating materials showed that assumption of superposition of the influences of temperature and moisture on the relative elongation is fully justified in this type of materials.

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