A QUICK METHOD OF MEASURING THE MOISTURE CHARACTERISTICS OF CAPILLARY-POROUS MATERIALS

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A method is described by which the moisture characteristics can be determined on the basis of the hygropotential, using an electrical probe of local moisture contents.

The physical complexity of heat and mass transfer processes in structural building materials makes it difficult to describe them analytically. The solutions to the equations of heat and mass transfer [1] are, as a rule, too complex for practical engineering calculations.

Using the hygropotential as a function of the moisture content and of the temperature is an expedient way to simplify the analytical description of the moisture transfer process, and it reduces this desorption to one equation of moisture conduction [2]:

$$\gamma_0 \eta(\Theta) \frac{\partial \Theta}{\partial \tau} = \frac{\partial}{\partial x}\left[K(\Theta) \frac{\partial \Theta}{\partial x}\right]. \quad (1)$$

The hygropotential in a material at definite temperatures and moisture content levels is found by balancing it against the moisture content in a reference specimen (filter paper), this latter moisture content converted also to the respective hygropotential Θ (u, t). Such conversions have been made on the basis of experiments for some materials, including structural materials [3, 4].

For calculations according to Eq. (1) one must know both the state and the transfer parameters of the moisture, referred to the hygropotential. The specific hygrocapacity is found by differentiating the moisture equilibrium curve. The hygroconductivity is determined from additional experiments.

The determination of moisture characteristics by the method of column slicing [4] is based on a steady-state process during which the hygrocurrent density follows the equation

$$j_m = -K(\Theta) \frac{\partial \Theta}{\partial x}. \quad (2)$$

This method has the drawbacks of other steady-state methods (long process time, departure of the actual field from the steady-state field, etc.). The determination of sought characteristics by solving, with the aid of a hydrointegrator, the reverse problem including also transient moisture fields [3] is rather complicated and not widely applicable.

The authors propose here a method of quickly determining the moisture characteristics, referred to the hygropotential, using an electrical probe of local moisture contents. In the general case, the analytical expressions for hygroconductivity and specific hygrocapacity (in (1) and (2)) are

$$K(\Theta) = \frac{j_m}{\partial \Theta / \partial x}, \quad (3)$$

$$\eta(\Theta) = \frac{\partial j_m / \partial x}{\partial \Theta / \partial \tau \gamma_0}. \quad (4)$$

These formulas are inconvenient for calculations, inasmuch as they require the knowledge of both the hygropotential and the hygrocurrent distribution along a space coordinate. After a change from space

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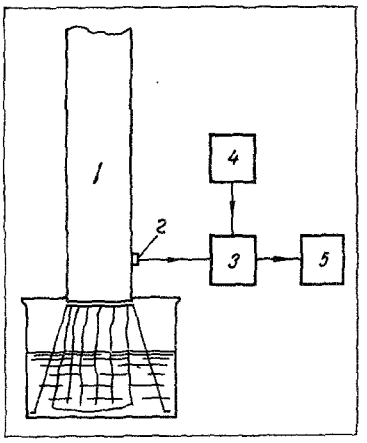

Fig. 1

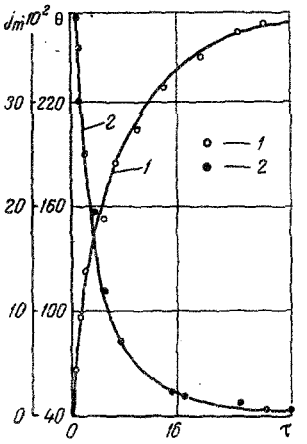

Fig. 2

Fig. 1. Block diagram of the test apparatus: 1) specimen of the test material, 2) capacitive probe, 3) instrument transducer, 4) high-frequency oscillator, 5) oscillograph.

Fig. 2. Curves of 1) hygropotential and 2) hygrocurrent density, as functions of time, at section x = 20 mm in the specimen of foam cement (γ_0 = 4900 N/m^3).

derivatives to time derivatives, the said quantities must be measured at one specimen section only. On the basis of the analogy between hygropotential and temperature, the substitution $\Theta = \Theta(\xi)$ ($\xi = x/\sqrt{\tau}$) with the boundary conditions and the initial conditions [5]

$$\Theta(0, \tau) = \Theta_1; \quad \frac{\partial\Theta(\infty, \tau)}{\partial x} = 0; \quad \Theta(x, 0) = \Theta_0 \tag{5}$$

will yield expressions for calculating the hygroconductivity and the specific hygrocapacity in the form

$$K(\Theta) = \frac{x j_m}{2\tau\partial\Theta/\partial\tau}, \tag{6}$$

$$\eta(\Theta) = \frac{2\tau\partial j_m/\partial\tau + j_m}{x\partial\Theta/\partial\tau\gamma_0}. \tag{7}$$

respectively. In order to use (6) and (7), one must have test data available on the variation of both the hygropotential and the hygrocurrent with time at one specimen section, i. e., of their local values.

The test procedure is as follows. A small capacitive probe of local moisture contents [6], which can be connected to a measuring instrument, is mounted on and fastened to one lateral surface at some distance from the base of a vertically arranged prismatic specimen. The lateral surfaces of this specimen are made moistureproof. The vertical specimen is placed on a pan in a vessel with water in such a way that its base remains in contact with permanently moist wicks. The starting time of the experiment is recorded together with the initial instrument reading, the latter corresponding to an equilibrium moisture content in the material. Instrument readings are further taken periodically and the time is always recorded too. The experiment is considered complete when the instrument readings cease changing with time, which corresponds to a constant hygrocurrent through the given specimen section. On the basis of these readings, one plots the hygropotential at that section as a function of time, with the instrument readings converted to hygropotential values according to the moisture equilibrium curve $\Theta = f(u, t)$. The hygrocurrent density at the given sections is found by the integration method [7] from moisture distribution curves for two sections. In this way, one obtains all the data necessary for determining the hygroconductivity and the specific hygrocapacity according to formulas (6) and (7).

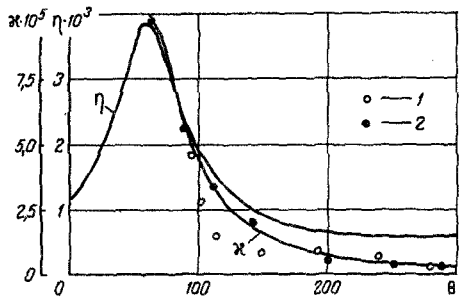

Fig. 3. Moisture characteristics of foam cement (γ_0 = 4900 N/m^3) at t = = 20°C: 1) hygroconductivity, according to the method described here, 2) hygroconductivity, according to the steady-state method.

The proposed method has been checked out on foam cement weighing $\gamma_0 = 4900\,N/m^3$. The specimen was 25 × 25 mm in cross section and 260 mm high. The probe was fastened to one lateral surface at x = 20 mm above the moist base. For recording the probe readings (the hygropotential), an instrument had been assembled with basically standard radioelectronic components, as shown schematically in Fig. 1. The operation of this instrument [8] made it possible to eliminate the effect of mineralized porous moisture on the results of measurements and, consequently, to eliminate the errors due to the migration of salts along with other water-soluble substances through the pores.

The results of our hygropotential and hygrocurrent measurements at section x = 20 mm are shown in Fig. 2.

With the aid of these data, the sought characteristics were calculated according to (6) and (7), as shown in Fig. 3.

The accuracy of these test results can be evaluated, if an analytical solution to the problem is known. Since there is no analytical solution to Eq. (1), hence a comparison is made here with the results obtained by the steady-state method. One must consider that the total error consists then not only of instrument errors and errors in graphical differentiation, but includes also the errors of the steady-state method. For comparison, in Fig. 3 has also been plotted the $K(\Theta)$ curve according to the steady-state method. The discrepancies between hygroconductivity values obtained by the quick method and by the steady-state method respectively, at the same hygropotentials, do not exceed 15%, which may be considered satisfactory for engineering applications.

A whole series of these tests at various temperatures will yield the moisture characteristics of capillary-porous materials over a wide temperature range.

The described method is not fast and technically easy to implement but, unlike other methods (steady-state as well as transient), it also avoids unwieldy analytical solutions in the form of series and the subsequent errors incurred by retaining only one term of a sum. Thus, for instance, a measurement of the said characteristics by the steady-state method required approximately 300 h, while a measurement of our proposed method required in the same case approximately 40 h. Furthermore, a single test by our method yields the moisture characteristics over a wide range of hygropotential values.

NOTATION

γ_0 is the specific weight of dry material;
η is the specific hygrocapacity;
Θ is the hygropotential;
τ is the time;
x is the height of a section above the moist base of a specimen;
K is the hygroconductivity;
jm is the hygrocurrent density.

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