DIFFUSION OF WATER THROUGH CERAMIC MIX IN ALTERNATING ELECTRIC FIELD

Part I – The diffusion pair method with an inner electric heat source

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The diffusion coefficient of water was determined by means of the diffusion pair method using an inner electric heat source and based on determining the moisture content profiles in pairs at various temperatures. The diffusion coefficient values obtained over the temperature range $T \in \langle 298K; 322.5K \rangle$ were approximated by the relationship

 $D = (1123.5 \exp(-7655/T))$ m² s⁻¹.

A comparison of the relationship obtained with that established by the same method without passage of alternating electric current proves that the effects of electric current speed up diffusion of water through a saturated porcelain mix with a saturated boundary.

INTRODUCTION

Water transfer in a saturated ceramic mix can be described mathematically as diffusion of water in a binary mixture of incompressible components, i.e. water and the ceramic material. In this case, the diffusion coefficient is a characteristic quantity of the water-saturated ceramic mix. It includes the effects of structure and composition on the transfer of water through the mix. Determination of the diffusion coefficient D by the diffusion pair method showed it to be independent of the amount of water in the mix but to be a function of temperature. The Dvalues are influenced by the state of the boundary [1-3]. An unsaturated boundary is formed between a water-saturated body and the environment, or between a saturated and an unsaturated body. Saturated boundaries exist between two saturated bodies.

For the case of saturated boundary, the following temperature dependence of the diffusion coefficient was found for a water-saturated porcelain mix:

$$D = 5.52 \cdot 10^{11} \exp(-14484/T)$$
 m² s⁻¹. (1)

The value of D is higher by one order for bodies with an unsaturated boundary. The difference is due to accelerated transfer of water by capillary suction in the menisci at the unsaturated boundary, i.e. to capillary barodiffusion [4-5]. Using the diffusion pair method with unsaturated boundary, or the method of drying under quasistationary conditions (i.e. a constant local rate of moisture loss and an invariable moisture profile) the following temperature dependence was established for saturated porcelain mix:

$$D_{\rm ef} = 3.93 \exp(-5645/T)$$
 m² s⁻¹ (2)

where D_{ef} is the effective diffusion coefficient including the effect of capillary barodiffusion.

The above findings on water transfer were made for a water-saturated ceramic mix whose temperature was changed by an external heat source. However, watersaturated ceramic mixes are also heated by an inner source of heat which is produced throughout the body by passage of alternating current at constant voltage.

The present study had the aim to determine the effect of alternating electric field on the transfer of water in water-saturated ceramic mix. For this purpose, it is first necessary to work out suitable methods for establishing the diffusion coefficient of water and its temperature dependence. The working out of the methods should be based on the electrical properties of the porcelain mix saturated with water or electrolyte (water with soluble salts). According to previous studies by the present authors [6-9] the flux of electric current through a saturated porcelain mix depends on electric potential and the concentration gradient of soluble salts in the mix. Electric conductance of the saturated mix does not depend on moisture content nor the moisture gradient, being a function of temperature and concentration of the salts. A water-unsaturated mix can be regarded as an insulant.

THE METHOD OF DIFFUSION PAIR WITH INNER ELECTRIC HEAT SOURCE

The diffusion coefficient of water or electrolyte in a water-saturated ceramic mix can be determined by the adjusted diffusion pair method [1] making use of unidirectional diffusion. With the use of the inner electric source of heat, the electrical properties of the mix allow the method to be applied solely to a diffusion pair composed of two water-saturated bodies with different moisture contents, i.e. to an unsaturated boundary.

Bodies 60 mm in length and 30 mm \times 30 mm in cross section were prepared from porcelain mix with a zero content of soluble salts [7] on a vacuum auger at moisture contents of C_1 and C_2 . The body surface was moisture-proofed to rule out exchange of moisture with the environment. The bodies were then kept for



Fig. 1. Schematic diagram of the diffusion pair method with an inner electric source of heat; 1, 2 — bodies with moisture content C₁, C₂, 3 — moisture proofing, 4 — electrodes, 5 — copper prisms, 6 — thermostat, 7 — voltmeter, 8 — ammeter, 9 — transformer, 10 — thermocouples.

48 hours to attain the initial homogeneous distribution of moisture througho the volume. After removing the moisture proofing coat on the body base, electro of conductive rubber were applied. The bodies were thermally insulated, connec to an electric circuit and heated separately to the required temperature by passi through electric current at a constant voltage. The temperature field in the bo was measured by a system of copper-constantan thermocouples. On attaining tak required temperature, a diffusion pair was created by joining the bases of two bodies. Following moisture proofing of the diffusion pair boundary with electrodes on the remaining bases of the bodies, the pair was placed between copper prisms according to Fig. 1. Water at temperature T was passing through the prisms. The heat generated inside the pair by the electric current was dissipated by the prisms. By a suitable control of voltage and water temperature, the required temperature of the pair was maintained with a negligible temperature gradient for time t. After that, the pair was rapidly cooled to T = 278 K and cut into transverse slices 3 mm in thickness in order to determine the moisture distribution.

From the moisture distribution thus established in one part of the diffusion pair, it is then possible to determine the diffusion coefficient, independent of moisture content, using the equation obtained by resolving the 2nd Fick law for a semiinfinite medium in the form

$$(C - C_s)/(C_1 - C_s) = \operatorname{erf} (x/2 \sqrt{Dt}), \qquad (3)$$

where x is the coordinate in the direction of diffusion, C_s is the moisture content by volume at the pair boundary. For moisture content by volume it holds that

$$C = (1 + (\varrho_L/\varrho_S) w^{-1})^{-1}, \tag{4}$$

where ϱ_L is the density of the compact component, ϱ_S is the density of the ceramic material, and w is the absolute moisture content, i.e. the ratio of the weight of water to that of the dry matter in the mix.

RESULTS OF THE MEASUREMENTS

The moisture distribution in the diffusion pair was measured three times for temperature T = 308 K. A typical moisture profile is shown in Fig. 2. The diffusion coefficients evaluated from the three measurements are given in Table I.



Fig. 2. Moisture profile at T = 308 K and t = 2820 s.

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The temperature dependence of the diffusion coefficient was measured over the temperature range $T \in \langle 298 \text{ K}; 322.5 \text{ K} \rangle$. Typical moisture profiles at 298 K and 322.5 K are shown in Fig. 3. The diffusion coefficients calculated for the individual temperatures are listed in Table II.



Fig. 3. Moisture profile in the diffusion pair; a - T = 298 K, t = 6960 s, b - T = 322.5 K, t = 2760 s.

| Table I | | | | | | | |
|---|-----|---|--|--|--|--|--|
| Diffusion coefficient of water at $T = 3$ | 308 | к | | | | | |

| $\frac{T}{K}$ | $\frac{D \cdot 10^8}{m^2 s^{-1}}$ | <u>ل</u> ۳² s ⁻¹ |
|---------------|-----------------------------------|--------------------------------|
| 308 | 2.19 2.18 2.23 | $(2.2 \pm 0.02) . 10^{-8}$ |

Table II Diffusion coefficient of water at various temperatures

| | 298 | 308 | 313 | 318 | 322.5 |
|------------------------------------|-----|-----|-----|-----|-------|
| $\frac{D \cdot 10^8}{m^2 s^{-1}}$ | 0.7 | 2.2 | 2.7 | 3.9 | 5.1 |

DISCUSSION OF RESULTS AND CONCLUSION

The results of the measurements show that the diffusion pair method with an inner heat source allows the diffusion coefficient of water in a saturated porcelain mix under the effect of alternating electric current to be determined reliably. The values of D obtained at various temperatures were approximated by the equation

$$D = (1123.5 \exp(-7655/T)), \qquad \mathrm{m}^2 \,\mathrm{s}^{-1} \tag{5}$$

which holds over the temperature range $T \in \langle 298 \text{ K}; 322.5 \text{ K} \rangle$.

A comparison of the temperature dependence of the diffusion coefficient during passage of electric current according to (5) with the dependence D = D(T)according to equation (1), determined for saturated ceramic mix by the same method but in the absence of an electric field, is shown in Fig. 4. The comparison indicates that over the entire temperature interval involved, the diffusion coefficient of water in water-saturated porcelain mix is higher in the presence of the electric field. For example, at T = 298 K and T = 305 K the difference amounts to one order or magnitude. The effect of an alternating electric field therefore accelerates diffusion of water through a saturated porcelain mix with a saturated boundary.



Fig. 4. Temperature dependence of the diffusion coefficient of water; 1 - from equation (5), 2 - fromequation (1).

References

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DIFÚZE VODY KERAMICKOU SMĚSÍ VE STŘÍDAVÉM ELEKTRICKÉM POLI

Část I. Metoda difúzního páru s vnitřním elektrickým zdrojem tepla

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Na stanovení difúzního koeficientu vody byla aplikována upravená metoda difúzního páru s vnitřním elektrickým zdrojem tepla, založená na stanovení vlhkostních profilů v páru při různých teplotách. Získané hodnoty difúzních koeficientů v rozmezí teplota $T \in \langle 298 \text{ K}; 322, 5 \text{ K} \rangle$ byly aproximovány vztahem

$$D = (1123,5 \exp(-7655/T))$$
 m² s⁻¹.

Porovnání získané závislosti se závislostí získanou stejnou metodou bez průchodu elektrického proudu dokazuje, že působení elektrického pole urychluje difúzi vody nasycenou porcelánovou směsí s nasyceným rezhraním.

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- Obr. 1. Schéma metody difúzního páru s vnitřním elektrickým zdrojem tepla; 1, 2 tělesa s vlhkostí
 C₁, C₂, 3 vlhkostní izolace, 4 elektrody, 5 měděné hranoly, 6 termostat, 7 voltmetr, 8 ampérmetr, 9 transformátor, 10 termočlánky.
- **Obr.** 2. Vlhkostní profil při T = 308 K a t = 2820 s.
- **Obr. 3.** Vlhkostní profil v difúzním páru; a T = 298 K, t = 6960 s, b T = 322.5 K, t = 2760 s.
- Obr. 4. Teplotní závislost difúzního koeficientu vody; 1 ze vztahu (5), 2 ze vztahu (1).

ДИФФУЗИЯ ВОДЫ КЕРАМИЧЕСКОЙ СМЕСЬЮ В ПЕРЕМЕННОМ ЭЛЕКТРИЧЕСКОМ ПОЛЕ

I. Метод диффузионной пары с внутренним электрическим источником тепла

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Для установления коэффициента диффузии воды применяли обработанный метод диффузионной пары с внутренним электрическим источником тепла, основывающийся на определении профилей влажности в паре при разных температурах. Полученные величины коэффициентов диффузии в пределах температур $T \in \langle 298 \ {\rm K} \ {\rm sccn.} \rangle$

 $D = (1\ 123,5\ \exp(-7\ 655/T))\ M^2c^{-1}.$

Сопоставление полученной зависимости с зависимостью, полученной с помощью одинакового метода без прохода электрического тока, показывает, что действие электрического поля ускоряет диффузию воды через насыщенную фарфоровую смесь с насыщенным разделом.

- Рис. 1. Схема метода диффузионной пары с внутренним электрическим источником тепла; 1, 2 — тела с влажностью С1, С2, 3 — влажностная изоляция, 4 — электроды, 5 — медные призмы, 6 — термостат, 7 — вольтметр, 8 — амперметр, 9 — трансформатор, 10 — термоэелементы.
- Рис. 2. Влажностный профиль при T = 308 К и t = 2820 с.
- Рис. 3. Влажностный профиль в диффузионной паре; а Т = 298 К, t = 6960 с, b Т b — Т = 322,5 К, t = 2760 с.
- Рис. 4. Температурная зависимость коэффициента диффузии воды; 1 из отношения (5), 2 из отношения (1).

Recenze knih

ED. KAMIMURA H., OSHIYMA A.: MECHANISMUS OF HIGH TEMPERA-TURE SUPERCONDUCTIVITY (Mechanismy vysokoteplotní supravodivosti). Springer Verlag, Berlin-Heidelberg 1989, cena neuvedena, 343 str., včetně 203 obr.

Kniha byla vydána v sérii Materials Science jako 11. díl. ye sborníkem 33 příspěvků z 2. symposia firmy NEC, které se konalo 24.—27. října 1988 v Hakone v Japonsku za účasti 48 předních pracovníků z Japonska, USA a Evropy.

Sborník sestává z 5 základních částí. Úvodní je přednáška objevitele vysokoteplotní supravodivosti prof. K. A. Müllera. Následuje 11 příspěvků týkajících se teoretických otázek. Třetí část tvoří 20 článků s experimentální problematikou s důrazem na vlastnosti a strukturu. Závěrečné části obsahují přednášku o supravodivosti systému Ba-K-Bi-O a závěry z diskusí sekce.

Kniha bude velmi užitečná pro specialisty zabývajícími se vysokoteplotní supravodivosti.

J. Kutzendorfer