Let us now calculate the relative bond strength in the case, for example, of chromium powder deposited on iron (or between chromium and iron powders sintered together) at a contact temperature of 900°K. Considering that the diffusion coefficient $D_{\pm}$ for vacancies in iron (D+) and chromium (D_) is $D_{\vartheta\pm} \approx D_{0\pm} \exp(-\Delta H^{m}_{\vartheta\pm} R^{-1} T^{-1})$ [3] (D_0 being a preexponential factor, ΔH^{m}_{ϑ} denoting the enthalpy of vacancy movement, related to the energy of diffusion activation E through the near-equality $\Delta H^{m}_{\vartheta} \approx 2^{-1}E$, and R denoting the universal gas constant), with $D_{0+} = 1.8 \cdot 10^{-5}$ m²/sec, $D_{0-} = 1.5 \cdot 10^{-8}$ m²/sec, $E_+ = 2.71 \cdot 10^5$ kJ/kmole, and $E_- = 2.21 \cdot 10^5$ kJ/kmole [3, p. 39], $n \sim 1.5$ and $a_+ \approx a_- \sim 2.5 \cdot 10^{-10}$ m [4], and $t \sim 10^{-5}$ sec (effective time of interaction in the contact region), we obtain with the aid of the table of probability integral [5, p. 129] $\varepsilon = \sigma\sigma_0^{-1} \sim 0.8$ for the relative bond strength. Assuming that σ_0 is equal to the adhesion energy for iron and chromium [6, p. 597], we obtain for the absolute bond energy $\sigma \sim 3.47$ J/m².

NOTATION

c, concentration of diffusible substance; x, coordinate normal to the boundary; t, time; D, diffusion coefficient; ε, relative bond strength (energy); E, energy of diffusion activation; T, temperature; and H, enthalpy.

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HEAT AND MOISTURE EXCHANGE OF NEWLY DENUDED ROCK MASSIF WITH A CHAMBER OF AN UNDERGROUND BUILDING

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The article presents formulas describing the fields of temperature and potential of moisture transfer in a massif, and also the dependences for calculating the heat and moisture flow from the massif into the air.

Exhausted underground spaces are widely used at present as stores, production spaces and premises for medical treatment, etc., and it becomes necessary to maintain certain temperature and moisture conditions in them. These disused workings very often have the shape of polyhedrons: parallelepipeds, prisms, etc. Existing methods of temperature and moisture calculation of cylindrical excavations [1, 2] cannot be used in similar cases. It is therefore expedient to examine the processes of heat and moisture exchange of air and a semi-bounded massif through a plane surface (wall).

It is known [2] that the processes of heat and mass exchange attain their greatest intensity in a newly denuded massif when the bulk of the moisture enters the air upon evaporation from the walls. In that case it may be assumed that the criterion of phase transformation in the massif is close to zero (ε ≈ 0) and the differential equation of heat and moisture transfer had the form [3]

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$$\frac{\partial T}{\partial \mathrm{Fo}_q}=\frac{\partial^2 T}{\partial x^2},\quad \frac{\partial V}{\partial \mathrm{Fo}_m}=\frac{\partial^2 V}{\partial x^2}+\delta\frac{t_s-t_c}{\theta_s-\theta_p}\frac{\partial T}{\partial \mathrm{Fo}_q} \tag{1}$$

with the boundary conditions

$$T(x,\ 0)=V(x,\ 0)=0,\ \text{for}\quad x\to\infty:\ T(x,\ \tau)\to 0,\ V(x,\ \tau)\to 0, \tag{2}$$

$$\frac{\partial T(1,\ \tau)}{\partial x}+\mathrm{Bi}_q[1-T(1,\ \tau)]-D'x_0[V(1,\ \tau)-1]=0, \tag{3}$$

$$\frac{\partial V(1,\ \tau)}{\partial x}+\delta\frac{t_s-t_c}{\theta_s-\theta_p}\frac{\partial T(1,\ \tau)}{\partial x}-\mathrm{Bi}_m[V(1,\ \tau)-1]=0, \tag{4}$$

where

$$T(x,\ \tau)=\frac{t(x,\ \tau)-t_s}{t_c-t_s},\quad V(x,\ \tau)=\frac{\theta(x,\ \tau)-\theta_s}{\theta_p-\theta_s},$$

$$D'=\frac{r\beta}{\lambda}\frac{\theta_s-\theta_p}{t_s-t_c}, \tag{5}$$

$$\mathrm{Fo}_q=\frac{a_q\tau}{x_0^2},\quad \mathrm{Fo}_m=\frac{a_m\tau}{x_0^2},\quad \mathrm{Bi}_q=\frac{\alpha x_0}{\lambda},\quad \mathrm{Bi}_m=\frac{\beta x_0}{\lambda_m}. \tag{6}$$

If we denote the mean values of the dimensionless temperature and potential of moisture transfer $\tilde{T}(1,\ \tau)$, $\tilde{V}(1,\ \tau)$, then we may introduce $\tilde{\alpha}$, $\tilde{\mathrm{Bi}}_q$, the reduced heat exchange and Biot coefficients by the formulas

$$\tilde{\alpha}=\alpha\left[1+\frac{D'}{\alpha}\frac{\tilde{V}(1,\ \tau)}{\tilde{T}(1,\ \tau)}\right],\quad \tilde{\mathrm{Bi}}_q=\tilde{\alpha}x_0/\lambda, \tag{7}$$

which enables us to write conditions (3) in the form

$$\frac{\partial T(1,\ \tau)}{\partial x}-\tilde{\mathrm{Bi}}_q T(1,\ \tau)+\mathrm{Bi}_q+D'x_0=0. \tag{8}$$

Furthermore, applying the Laplace–Carson transformation [4] to Eqs. (1) with the conditions (2), (4), (8), we obtain expressions of the dimensionless temperature and potential of moisture transfer

$$T(x,\ \tau)=\frac{t(x,\ \tau)-t_s}{t_c-t_s}=\frac{\mathrm{Bi}_q+D'x_0}{\tilde{\mathrm{Bi}}_q}\left\{\mathrm{erfc}\,\frac{x-1}{2\sqrt{\mathrm{Fo}_q}}-\exp[(x-1)\tilde{\mathrm{Bi}}_q+\tilde{\mathrm{Bi}}_q^2\mathrm{Fo}_q]\,\mathrm{erfc}\left(\tilde{\mathrm{Bi}}_q\sqrt{\mathrm{Fo}_q}+\frac{x-1}{2\sqrt{\mathrm{Fo}_q}}\right)\right\}, \tag{9}$$

$$V(x,\ \tau)=\frac{\theta(x,\ \tau)-\theta_s}{\theta_p-\theta_s}=a_3\left\{\mathrm{erfc}\,\frac{x-1}{2\sqrt{\mathrm{Fo}_m}}-\exp[(x-1)\mathrm{Bi}_m+\mathrm{Bi}_m^2\mathrm{Fo}_m]\times\right.$$

$$\left.\times\,\mathrm{erfc}\left(\mathrm{Bi}_m\sqrt{\mathrm{Fo}_m}+\frac{x-1}{2\sqrt{\mathrm{Fo}_m}}\right)\right\}-b_3\left\{\mathrm{erfc}\,\frac{x-1}{2\sqrt{\mathrm{Fo}_m}}-\exp[(x-1)\tilde{\mathrm{Bi}}_q\sqrt{a_q/a_m}+\mathrm{Bi}_q^2\mathrm{Fo}_q]\right. \tag{10}$$

$$\left.\mathrm{erfc}\left(\tilde{\mathrm{Bi}}_q\sqrt{\mathrm{Fo}_q}+\frac{x-1}{2\sqrt{\mathrm{Fo}_m}}\right)\right\}+c_3\left\{\mathrm{erfc}\,\frac{x-1}{2\sqrt{\mathrm{Fo}_q}}-\exp[(x-1)\tilde{\mathrm{Bi}}_q+\tilde{\mathrm{Bi}}_q^2\mathrm{Fo}_q]\,\mathrm{erfc}\left(\tilde{\mathrm{Bi}}_q\sqrt{\mathrm{Fo}_q}+\frac{x-1}{2\sqrt{\mathrm{Fo}_q}}\right)\right\}.$$

We find the coefficients of nonsteady heat and mass exchange by the formulas [2]

$$k_\tau=-\frac{\lambda}{x_0}\frac{\partial T(1,\ \tau)}{\partial x},\quad m_\tau=-\frac{\lambda_m}{x_0}\frac{\partial V(1,\ \tau)}{\partial x}. \tag{11}$$

Using (4), (8), (9), and (10), we write

$$k_\tau=\frac{\lambda}{x_0}(\mathrm{Bi}_q+D'x_0)[1-f(z_q)], \tag{12}$$

$$m_\tau=\frac{\lambda_m}{x_0}\left[\delta\frac{t_s-t_c}{\theta_s-\theta_p}(\mathrm{Bi}_q+D'x_0)+\mathrm{Bi}_m(b_3-c_3)\right]f(z_q)-\frac{\lambda_m}{x_0}\mathrm{Bi}_m a_3 f(z_m)+\frac{\lambda_m}{x_0}\left[\mathrm{Bi}_m-\delta\frac{t_s-t_c}{\theta_s-\theta_p}(\mathrm{Bi}_q+D'x_0)\right], \tag{13}$$

where

$$a_3=1-\delta\frac{t_s-t_c}{\theta_s-\theta_p}\frac{\mathrm{Bi}_q+D'x_0}{\mathrm{Bi}_m}\frac{\tilde{\mathrm{Bi}}_q-\mathrm{Bi}_m(\sqrt{a_m/a_q}+a_q/a_m-1)-1}{(a_q/a_m-1)(\tilde{\mathrm{Bi}}_q-\mathrm{Bi}_m\sqrt{a_m/a_q})}, \tag{14}$$

$$b_3 = \delta \frac{t_s - t_c}{\theta_s - \theta_p} \frac{\mathrm{Bi}_q + D'x_0}{\tilde{\mathrm{Bi}}_q \sqrt{a_q/a_m} - \mathrm{Bi}_m} \left[1 + \frac{\tilde{\mathrm{Bi}}_q - \mathrm{Bi}_m}{\tilde{\mathrm{Bi}}_q (a_q/a_m - 1)} \right], \tag{15}$$

$$c_3 = \delta \frac{t_s - t_c}{\theta_s - \theta_p} \frac{\mathrm{Bi}_q + D'x_0}{\tilde{\mathrm{Bi}}_q (a_q/a_m - 1)}, \tag{16}$$

$$f(z) = 1 - \exp(z^2) \operatorname{erfc}(z) \quad z_q = \tilde{\mathrm{Bi}}_q \sqrt{\mathrm{Fo}_q},\ z_m = \mathrm{Bi}_m \sqrt{\mathrm{Fo}_m}, \tag{17}$$

$$\operatorname{erf} x = \frac{2}{\sqrt{\pi}} \int_0^x \exp(-y^2)\, dy,\ \operatorname{erfc} x = 1 - \operatorname{erf} x. \tag{18}$$

The dependence (12), (13) enable us to calculate the flows of heat and moisture by the formulas

$$q = k_\tau (t_s - t_c),\ m = m_\tau (\theta_s - \theta_p), \tag{19}$$

where $k_\tau = \Sigma k_{\tau i} F_i / \Sigma F_i$, $m_\tau = \Sigma m_{\tau i} F_i / \Sigma F_i$ are the mean values on all the sides.

NOTATION

$\bar{x}$, dimensional coordinate; x_0, characteristic dimension, half the distance between opposite sides of the chamber; $x = \bar{x}/x_0$, dimensionless coordinate; $t(x, \tau)$, temperature of the massif; t_c, t_s, temperature of the air and of uncooled soils; $\theta(x, \tau)$, potential of moisture transfer; θ_s, θ_p, its value in the bulk of the massif and its equilibrium value, respectively; c_q, c_T, specific heat and moisture capacity, respectively; λ, λ_m, heat and moisture conductivity, respectively; $a_q = \lambda/c_q\gamma_0$, thermal diffusivity; $a_m = \lambda_m/c_T\gamma_0$, potential conductivity of moisture transfer; r, specific heat of phase transition; ε, criterion of phase transformation ($0 \le \varepsilon \le 1$); δ, Soret coefficient; α, heat-exchange coefficient; β, mass-exchange coefficient.

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