A NONISOTHERMAL METHOD OF INVESTIGATING THE SINTERING KINETICS OF MATERIALS CONTROLLED BY TWO MECHANISMS

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According to V. A. Ivensen's phenomenological theory of sintering [1], the sintering kinetics of crystalline powders is determined by two parallel processes - flow of material due to crystal lattice imperfections and removal of imperfections, which are described by the following equations of the first and second orders:

\[ Z' = -\kappa N \exp \left( -\frac{E_\kappa}{RT} \right) \frac{dZ}{d\tau} \]
\[ N' = -\nu \exp \left( -\frac{E_\nu}{RT} \right) \frac{dN}{d\tau} \]

where \( Z \) and \( N \) are parameters characterizing the degree of sintering of the material

\[ \left[ \frac{\rho\left(\rho - \rho_i\right)}{\rho_i \left(\rho - \rho_i\right)} \right] \frac{dZ}{d\tau} = \frac{1 - \gamma}{Y_m} \text{etc.} \]

and the concentration of crystal lattice imperfections, \( E_\kappa \) and \( E_\nu \) are the energies of activation of the processes under consideration, \( T \) is the temperature, \( \tau \) is the time, \( R \) is the gas constant, \( \kappa \) and \( \nu \) are constants, \( \rho \), \( \rho_i \), and \( \rho_{tr} \) are, respectively, the instantaneous, initial, and true densities of the material, \( \gamma \) is the instantaneous linear specimen shrinkage, \( Y_m \) is the maximum linear specimen shrinkage on the attainment of the true density of the material,

\[ Z' = \frac{dZ}{d\tau} \] and \[ N' = \frac{dN}{d\tau} \]

On the basis of formulas (1) a kinetic equation of isothermal sintering has been obtained and an isothermal method has been developed for determining its constants [1]. However, determination of kinetic constants by this method is inevitably linked with errors due to the influence of the time of heating-up of specimens to the sintering temperature, which in some cases is quite long. Such errors can be eliminated by using a nonisothermal method, which possess high specific informativeness and guarantees fitness of kinetic parameters in the whole range of heating rates investigated. The latter is particularly important in calculations of sintering processes involving ceramic materials, which in industrial practice as a rule take place under nonisothermal conditions or are appreciably affected by heating rates [2].
If $T = \text{const}$, the following kinetic equation is obtained from Eqs. (1) for nonisothermal conditions:

$$Z' = -\frac{xN_0 \exp \left( -\frac{E_x}{RT} \right)}{1 + yN_0 \int_{\tau} \exp \left( -\frac{E_y}{RT} \right) d\tau} Z.$$

It will be seen that, at a heating rate $b = 0$, i.e., under isothermal conditions, this equation becomes

$$Z' = -\frac{xN_0 \exp \left( -\frac{E_x}{RT} \right)}{1 + yN_0 \exp \left( -\frac{E_y}{RT} \right)} Z,$$

which is analogous to the equation in [1].

In the nonisothermal method of kinetic investigation the heating of specimens is effected according to the linear law

$$T = T_0 + b\tau,$$

where $b = dT/d\tau = \text{const}$ is the heating rate and $T_0$ is the specimen temperature at the initial instant of time.