The temperature stresses in polyethylene composites with fibrous fillers have been estimated. It is shown that they do not represent a threat to the adhesion bond or the cohesion strength of the components of the systems investigated. Model experiments have revealed the presence of an adhesion interaction between the filler and the matrix in the composite itself and have made it possible to estimate the actual threat posed by the temperature stresses. The mechanism of action of the filler particles on the thermal expansion of the composite is explained.

The present article is a continuation of a series of studies devoted to the investigation of the effect of fillers on the thermophysical and antifriction properties of polyethylene. It has already been shown [1-4] that, when fillers with a higher Young's modulus and lower coefficient of thermal expansion as compared with the starting polymer are introduced into polyethylene, the properties of the latter can be considerably improved. Thus, the strength is increased, the coefficient of friction is reduced, the wear resistance is raised by several orders, and the linear coefficient of thermal expansion is reduced by an order (and may reach a value less than that for metals). This opens the way for the creation of bearing materials with high antifriction properties. However, bearings operate under variable heating and cooling conditions, so that internal stresses inevitably develop in the composite material. Moreover, temperature stresses are produced directly in the process of obtaining the composite. It is therefore necessary to estimate the magnitude of the internal stresses in the composites investigated and their effect on the adhesion between the polyethylene and the filler surface and on the performance of the material as a whole.

The present article is devoted to a study of the processes that take place at the polymer-filler interface.

Temperature Stresses in Composite

We will examine the temperature stresses that develop in a composite based on thermoplastic polymer filled with fibrous particles with a high Young's modulus and a low coefficient of thermal expansion. When the composite is heated (cooled), if the adhesion bond between the matrix and the fiber is sufficiently strong, they deform together. As a result of the considerable difference in the coefficients of thermal expansion shear stresses develop at the interface. Consequently, stresses acting in the longitudinal direction (along the fiber) are created in the fiber and the matrix. Moreover, the fact that the thermal shrinkage of the resin is much greater than the shrinkage of the fiber results in the creation of radial and circumferential stresses during the fabrication process [5].

Thus, in order to characterize the state of stress at the interface it is necessary to determine: 1) the tangential stresses \( \tau \); 2) the tensile (or compressive) stresses in the fiber \( \sigma_f \); 3) the tensile (or compressive) stresses in the matrix \( \sigma_m \); 4) the radial stresses in the fiber \( \sigma_{rad f} \); 5) the radial stresses in...
The model of an element of the composite material includes: 1) the stresses in the fiber \( \sigma_{\text{f}} \); 2) the stresses in the matrix \( \sigma_{\text{m}} \); 3) the radial stress \( \sigma_{\text{rad}} \) in the fiber; 4) the longitudinal stress \( \sigma_{\text{z}} \) in the fiber; 5) the circumferential stresses in the fiber \( \sigma_{\text{t}} \); 6) the circumferential stresses in the matrix \( \sigma_{\text{tm}} \) (2, 3 act along the fiber; 4, 5, 6, 7 are mechanical shrinkage forces). These stresses are not constant, but vary both along the length of the fiber and with distance from its surface. The tangential stresses reach maximum values at the ends of the fiber and rapidly fall off toward the center. The tensile stresses are maximal at the center of the fiber and after the critical fiber length is exceeded remain constant [6]. If a continuous fiber is employed, the edge effects may be neglected and the normal stresses may be assumed constant and equal to the maximum value for a fiber of the given diameter. The radial and circumferential stresses have maxima at the contact surface and fall off sharply with distance from the fiber [7].

In order to obtain a quantitative estimate of the internal stresses we solved the problem of the thermal deformation of a model composition consisting of a plastic matrix and a reinforcing fiber whose length is equal to the length of the matrix (i.e., a continuous fiber). It should be noted that in this formulation the problem of the thermal stresses is not solved by determining all the stresses mentioned above [8, 9]. The model possesses axial symmetry (Fig. 1). It is required to determine the longitudinal (z axis) and radial (x, y axes) stresses that develop in the fiber and the matrix during cooling (heating).

We write the equations of the generalized Hooke's law in the form

\[
\varepsilon_x = \sigma_x / E - \mu \varepsilon_y / (\sigma_y + \sigma_z), \quad \varepsilon_y = -\sigma_y / E - \mu \varepsilon_x / (\sigma_x + \sigma_z), \quad \varepsilon_z = -\sigma_z / E - \mu \varepsilon_y / (\sigma_y + \sigma_z),
\]

where \( \varepsilon_x, \varepsilon_y, \varepsilon_z \) are the model strains along the x, y, z axes; \( \sigma_x, \sigma_y, \sigma_z \) are the stresses in the model model along the x, y, z axes; \( \mu \) is Poisson's ratio; \( E \) is Young's modulus. In the case in question \( \sigma_x = \sigma_y = \sigma_{\text{rad}} \) and \( \varepsilon_x = \varepsilon_y = \varepsilon_{\text{rad}} \). Obviously, the sum of the relative strains of the matrix and the fiber in both a longitudinal and transverse directions is equal to the difference of their temperature strains

\[
\varepsilon_{zm} + \varepsilon_{zf} = (a_{zm} - a_{zf}) \Delta T; \quad \varepsilon_{radm} + \varepsilon_{radf} = (a_{zm} - a_{zf}) \Delta T \tag{2}
\]

(all the notation with subscripts "f" and "m" relates to the fiber and the matrix, respectively), if it is assumed that \( I_0 (1 + \alpha \Delta) \equiv I_0 \).

From the condition of equilibrium of the composite in the longitudinal direction we obtain \( \sigma_{zm} S_m = \sigma_{zf} S_f \) or \( \sigma_{zm} = \sigma_{zf} S_m / S_f = K \sigma_{zf} \), where \( S_f \) and \( S_m \) are the cross-sectional areas of the fiber and the matrix, respectively. The equilibrium condition in the radial direction gives \( \sigma_{radm} = \sigma_{radf} \).

Using the Lamé solution for the axisymmetric problem, we can establish a relation between the radial \( \sigma_{rad} \) and circumferential \( \sigma_{t} \) stress components.

In order to determine the stresses in the composite when the temperature changes by \( \Delta T \) it is necessary to solve a system of nine equations in nine unknowns

\[
\begin{align*}
\varepsilon_{zm} &= \sigma_{zm} / E - 2\mu \varepsilon_{zf} / E - \sigma_{zf} / E; \\
\varepsilon_{zf} &= -\sigma_{zf} / E - 2\mu \varepsilon_{zm} / E - \sigma_{zm} / E; \\
\varepsilon_{zm} + \varepsilon_{zf} &= (a_{zm} - a_{zf}) \Delta T; \\
\sigma_{zm} &= \sigma_{zm} / E - \mu \varepsilon_{zm} / E; \\
\sigma_{zf} &= -\varepsilon_{zf} / \mu E - \mu \varepsilon_{zm} / E; \\
\sigma_{radm} &= \sigma_{radf} / E - \mu \varepsilon_{zm} / E; \\
\sigma_{radf} &= \sigma_{radf} / E - \mu \varepsilon_{zm} / E; \\
\sigma_{zm} &= K \sigma_{zf}; \\
\sigma_{radm} &= \sigma_{radf}; \\
\sigma_{zf} &= \beta \sigma_{radf}.
\end{align*}
\tag{3}
\]