DIELECTRIC AND THERMOPHYSICAL PROPERTIES OF FILLED POLYETHYLENE

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UDC 536.2:678.742

Following is a presentation of experimental results obtained in a study of the thermophysical and the dielectric properties of P4040-L polyethylene filled with wood flour.

Wood-flour-filled P4040-L polyethylene is a typical thermoplastic material. It is mechanically very strong, highly heat resistant, durable, and reliable, which justifies its wide use in radio engineering work as well as in other branches of industry [1, 2].

In order to put a thermoplastic material to a practical use, one must know not only its mechanical but also its dielectric and thermophysical properties. However, data on the temperature and dielectric characteristics of this material are lacking.

We will present here the experimental results obtained in a study of these characteristics for wood-flour-filled P4040-L polyethylene.

P4040-L high-density ($\gamma = 941$-$943\ \mathrm{kg/m^3}$) polyethylene is a product of ethylene polymerization under low pressure; the polymer structure is 85% crystalline, its molecular weight is 10^4-$3 \cdot 10^6$, and the macromolecular chain is linear; $\lambda = 0.352$ W/m·deg, $c_p = 1.32$ J/kg·deg, $\tan\delta = 2.1 \cdot 10^{-4}$, $\varepsilon = 2.4$, $\rho_v = 1.8 \cdot 10^{14}$ [3].

Wood flour, the polyethylene filler, is ground shavings produced in processing the timber of coniferous trees. At T = 290°K: $\lambda_{mean} = 0.306$ W/m·deg, $a = 1.07 \cdot 10^{-7}\ \mathrm{m^2/sec}$, $c_p = 2.56 \cdot 10^3$ J/kg·deg [4].

The dielectric loss tangent $\tan\delta$ and permittivity ε were determined on flat specimens 50 mm in diameter with a KV-1 coulometer at the 1.5 MHz frequency [5]. The volume resistivity and the surface resistivity were determined on flat specimens 26 mm thick with an F-507 teraohmmeter [5]. The thermophysical properties (conductivity λ, diffusivity a, specific heat c_p) were determined with an apparatus shown in [6].

The tests were made on cylindrical specimens with the following geometrical dimensions: $l = 120$ mm, d = 40 mm. Three holes $l/2$ deep were drilled lengthwise at locations marked on a radius. A copper–constantan thermocouple for measuring the absolute temperatures within a 0.1° accuracy was installed along the specimen axis. A differential thermocouple for measuring small temperature differences within a 0.01° accuracy was installed in each of the other two holes parallel to and at the respective distances of 6 mm and 12 mm from the axis. A heater coil of 0.2 mm constantan wire was wound tightly around the cylindrical surface of the specimen and bonded to it with Bakelite varnish. Such a specimen assembly ensured a temperature field sufficiently uniform in the axial direction for the duration of the test.

The thermophysical characteristics of wood-flour-filled P4040-L polyethylene were studied in the 273-373°K temperature range. A specimen was heated at a constant rate of 1-3°C/min. The power drawn for heating a specimen was 4.5-5.0 W.

The error in determining the dielectric properties did not exceed 4%, in determining the thermophysical properties 5%.

Institute of Heat and Mass Transfer, Academy of Sciences of the BSSR; Institute of Radio Engineering, Minsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 18, No. 5, pp. 856-859, May, 1970. Original article submitted June 2, 1969.

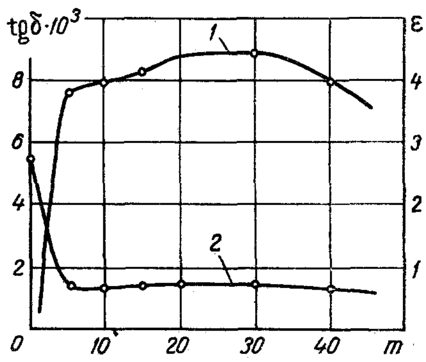

Fig. 1

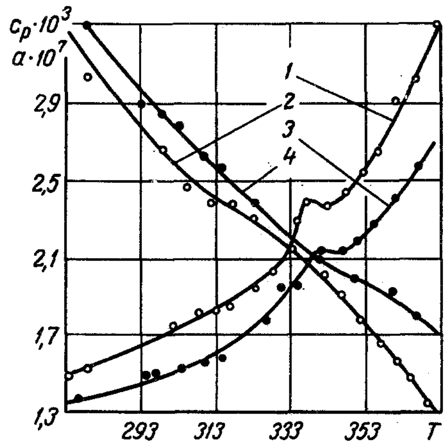

Fig. 2

Fig. 1. Tan δ and ε of P4040-L polyethylene as functions of the wood-flour content (m, %): 1) tangent of dielectric loss angle; 2) dielectric permittivity.

Fig. 2. Curves of $c_p = f(T)$, and $a = f(T)$: 1, 2) represent the specific heat and the thermal diffusivity of a 90 : 10 P4040-L polyethylene–wood flour mixture; 3, 4) represent the specific heat and the thermal diffusivity of a 50 : 50 P4040-L polyethylene–wood flour mixture.

In Fig. 1 are shown the dielectric characteristics (tan δ, ε) of low-pressure P4040-L polyethylene as functions of the wood-flour content. It is evident from the diagram that the addition of filler increases the dielectric losses. The sharp increase of tan δ results from an addition of polarly oriented filler clusters into the polyethylene [10], while the magnitude of dielectric losses is particularly sensitive to small concentrations – up to 5% – of filler material. The maximum increase of tan δ occurs when the filler content is 25-30%, beyond which it again decreases.

The dielectric permittivity decreases sharply as 5% wood flour is added. With a further addition of filler it does not change, remaining almost constant. The volume resistivity and the surface resistivity decrease with the addition of filler.

In Figs. 2 and 3 are shown the thermophysical temperature characteristics of P4040-L polyethylene –wood flour mixture. The diagram indicates that the thermal diffusivity of the mixture decreases as the temperature increases over its entire range.

The specific heat increases with higher temperature, and moderate maxima are observed at T = 335-338°K. In the authors' opinion, the presence of local maxima results from a change in the polyethylene structure when it is heated together with the filler. The structural transition of the polymer brings about a release of heat and a lowering of the specific heat. This hypothesis is confirmed by the sharp increase in the thermal diffusivity at the said temperatures.

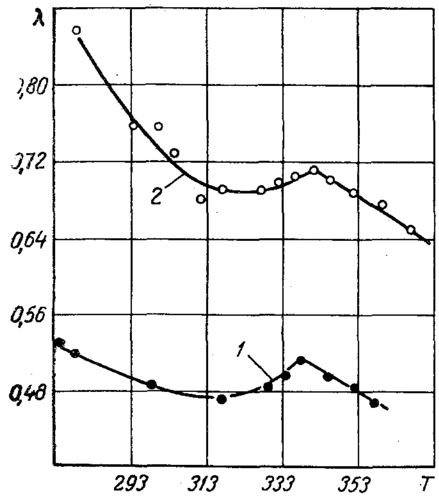

Fig. 3. Curves of λ = f(T) for the following mixtures: 1) 90% P4040-L polyethylene and 10% wood flour; 2) 50% P4040-L polyethylene and 50% wood flour.

The possibility that such a process occurs during heating has been hinted at in [7, 8, 9].

The addition of 50% filler causes a shift of the maximum toward 3-5°C higher transition temperatures than for polyethylene with 10% filler.

The amounts of polyethylene and wood flour in the mixture were measured in percentages of total mass.

NOTATION

ρ is the density;
λ is the thermal conductivity;
c_p is the specific heat;
a is the thermal diffusivity;
$\tan\delta$ is the tangent of the dielectric loss angle;
ε is the dielectric permittivity;
ρ_v is the volume resistivity;
m is the filler content, %.

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