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HEAT CONDUCTIVITY OF THIN-LAYER POLYMERIC MATERIALS TREATED BY A MAGNETIC FIELD

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The influence of a constant magnetic field on the heat conductivity of thin-layer polymeric materials with a ferromagnetic filler at the stage of their hardening has been investigated. It is shown that multicomponent fillers and a pulsating magnetic field do a good job for obtaining polymeric materials possessing a high heat conductivity.

Thin-layer polymeric materials in the form of films, gaskets, adhesive interlayers, and coatings are used in radio electronics, communication systems, and low-power engineering. In many cases, the use of these materials is limited by their low heat conductivity. It is known that the heat conductivity of thin-layer polymeric materials can be increased by introduction of metal powders into their polymer matrix [1]. However, this method is inefficient and, as a rule, degrades the mechanical characteristics of a material. The indicated problem can be solved if a heat-conducting structure of a disperse filler is formed in a polymer by orientation of it in a constant magnetic field. It was established in [2] that the introduction of a disperse filler into the polymer matrix of a material leads to its "disturbance," with the result that the structure of the material changes at the molecular, topological, and supermolecular levels. This, in turn, leads to the formation of polymeric compounds with properties differing from the properties of the polymer in the matrix state.

According to the classical postulates of the polymer-chemistry theory [3], the formation of ordered structures of the particles of a filler in a polymer material depends substantially on the interaction of the polymer with the filler. Let us denote the energy of interaction between the molecules of a polymer by A_{11}, the energy of interaction between the particles of a filler by A_{22}, and the energy of interaction between the polymer macromolecules and the filler particles by A_{12}. Several variants of interaction of a polymer with a filler are possible. For example, if $A_{11} > A_{12}$ and $A_{22} > A_{12}$, a mixing of the components leads to the appearance of a large number of agglomerates of filler particles preventing the formation of a heat-conducting structure. If $A_{12} > A_{11}$ and $A_{22} > A_{12}$, fairly strong bonds of the polymer with the filler are formed, with the result that each particle of the filler is covered by a polymer layer and the strength of the system increases.

In the case where $A_{22} > A_{12}$ and $A_{22} > A_{11}$, the heat conductivity of a polymeric system is highest. This condition can be provided by magnetic orientation of the particles of a ferromagnetic filler in the polymer matrix. The filler particles are magnetized under the action of a magnetic field and interact with each other, with the result that along the line of force of the magnetic flux there arise chains of filler particles forming structures with a high heat conductivity.

Experimental. In order for the method proposed to be realized in practice, 1) the filler must possess ferromagnetic properties, 2) the polymer must have a low viscosity, and 3) the polymer must be capable of rapid hardening making possible the fixation of the heat-conducting structures of the filler particles formed under the action of the magnetic field.

The samples whose heat-conduction properties were investigated were obtained on a specially developed setup, the main elements of which are an electromagnetic inductor with moving shoes, a power unit, and a thermal chamber with heat-measuring apparatus. This setup makes it possible to form a constant magnetic field with a strength of up to $32 \cdot 10^4$ A/m, controlled by changing the current in the winding of a magnet and the distance between the poles of the setup.

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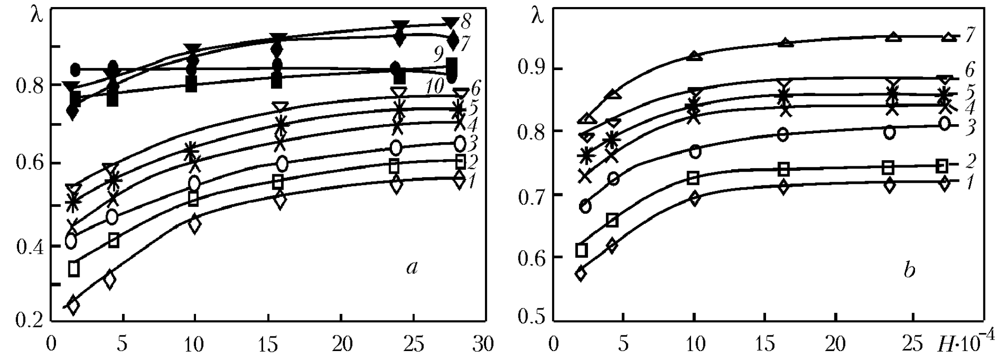

Fig. 1. Dependence of the heat-conductivity coefficient of magnetic-field treated polymeric gaskets with a disperse MIP filler on the strength of a constant magnetic field (a) and the strength of a pulsating magnetic field (b): 1) C = 10 (1), 20 (2), 30 (3), 40 (4), 50 (5), 60 (6), 70 (7), 80 (8), 90 (9), and 100 wt.% (10). λ, W/(m·K); N, A/m.

The investigation objects were gaskets and adhesive interlayers of a polymeric compound entering into the composition of a low-molecular EDR epoxy resin with a filler of polyethylene polyamine and a softener of dibutyl phthalate in the amount of 10 wt.% of the resin. The fillers were a ferromagnetic iron powder of type MIP (microatomized iron powder) with particles of average size 20–40 μm and a nickel powder of type NCP (nickel carbonyl powder) of different dispersity. Polymer gaskets in the form of disks of diameter 30 mm and thickness of 1 mm were cast in a special fluoroplastic cuvette placed together with a heating chamber in the space between the poles of the setup. Samples with an adhesive interlayer of thickness 0.5–1 mm were placed between the 12Kh18N10T-steel substrates. The gaskets and interlayers were hardened at a temperature of 70–80°C. The duration of one treatment of samples in a magnetic field did not exceed 30 min.

The heat conductivity of the samples obtained was investigated on a setup functioning on the basis of the method of two-temperature time intervals [4].

Results and Discussion. Figure 1a presents results of investigations of gaskets treated by a magnetic field. It is seen that the heat-conductivity coefficient of the material of the gaskets λ increases with increase in the magnetic-field strength H independently of the concentration of a filler. Such behavior of the dependences $\lambda = f(H)$ at different concentrations of the filler is explained by the fact that the number of heat-conducting chain structures of the filler increases with increase in the field strength. At a small filler concentration, the curve $\lambda = f(H)$ practically degenerates beginning with the field strength $H > 24 \cdot 10^4$ A/m. For gaskets of compounds charged more heavily, this process shifts to the region where the field strength is higher. This is explained by the increase in the number of particles participating in the structurization of the heat-conducting formations.

It also follows from Fig. 1a that, at a filler concentration of $C > 80$ wt.%, the heat conductivity of the gasket material decreases (curves 9, 10). This anomaly can be explained by the fact that a regime of filler supersaturation is established that leads to the formation of gaseous inclusions decreasing the heat conductivity of the material.

Figure 2a shows the dependences $\lambda = f(H)$, obtained for interlayers of adhesive compounds with fillers of different concentrations. As is seen, these dependences are identical to the dependences shown in Fig. 1a. The small decrease in the absolute heat conductivity of the adhesive interlayers, represented in Fig. 2, can be explained by the fact that, in the process of hardening of these interlayers, there arise in them internal stresses extending the macromolecules along the surfaces of the substrates [5]. In essence, the anisotropy of the heat conductivity of the adhesive interlayers manifests itself in this case.

To determine the influence of the nature of a filler on the process being considered, we investigated the dependence of the heat-conductivity coefficient of polymer gaskets of a compound based on epoxy resin with NCP nickel powder on this parameter. The behavior of the dependences $\lambda = f(H)$ shown in Fig. 2b differs insignificantly from the behavior of the analogous dependences obtained for gaskets with iron powder (see Fig. 1a); however, the heat conductivity in the first case is higher in absolute value. This can be explained by the fact that nickel has a higher heat conductivity than iron. At the same time, we carried out investigations on the influence of the dispersion

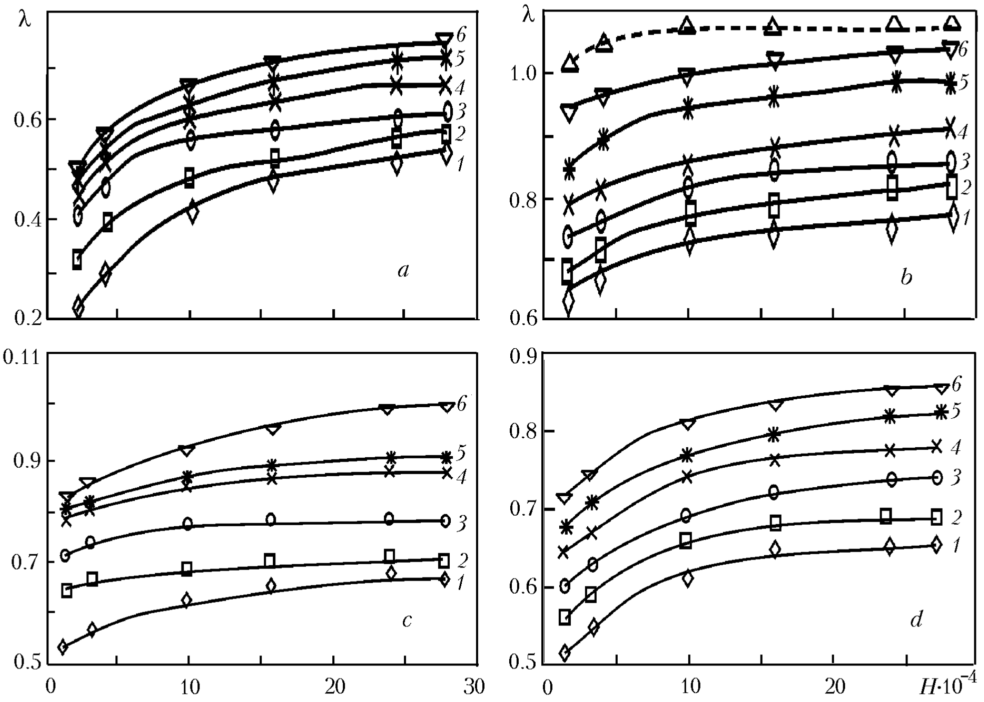

Fig. 2. Dependence of the heat-conductivity coefficient of adhesive interlayers with a disperse MIP filler (a) and of polymeric gaskets with disperse fillers of NCP (b), MIP + 10 wt.% of a graphite powder (c), and MIP + 10 wt.% of a brass powder (d), treated by a magnetic field, on the strength of this field. Designations 1–6 are identical to those in Fig. 1. λ, W/(m·K); *N*, A/m.

of the filler on the heat conductivity of the polymer. Curves 1–6 in Fig. 2b were obtained for gaskets containing a filler with particles of reduced diameter d = 30–40 μm. The dashed line represents the results of investigations of the filler with particles of diameter d = 300–400 μm at a concentration of C = 60 wt.%. It is seen that, in the latter case, the heat conductivity is much higher than that of polymer gaskets with a higher-dispersed filler. In this case, the increase in the heat conductivity is due to the decrease in the number of contacts between the particles of the filler in the chain structures formed under the action of the magnetic field. This leads to a decrease in the total contact thermal resistances and, as a result, to an increase in the heat conductivity of the gasket [5].

The method proposed does not exhaust the possibilities of increasing the heat conductivity of thin-layer polymeric materials. This can be made using two other technological procedures presented below.

The first procedure involves the introduction of a two-component mixture of disperse fillers, one of which possesses ferromagnetic properties, into the polymeric compound. Figures 2c and d present the dependences $\lambda = f(H)$ for polymeric gaskets of compounds with fillers of MIP + graphite powder and MIP + brass powder of different concentrations. It is seen that the heat conductivity of these gaskets is increased as compared to that of the gaskets whose dependences are presented in Fig. 1a. The increased heat conductivity of polymers with multicomponent fillers is explained by the fact that the particles of a nonferromagnetic-nature filler have a tendency to concentrate near the structures formed under the action of a magnetic field [6] and by their higher heat conductivity.

Central to the second technological procedure for increasing the heat conductivity of thin-layer polymeric materials is increasing the density of packing of the particles of a filler by decreasing the contact thermal resistances at the points of their mutual contact. For this purpose, a product is acted upon by a pulsating magnetic field formed by periodically changing the strength of the current in the winding of an electromagnet at a period when a binder is polymerized. Comparison of the graphs in Fig. 1a and b shows that the heat conductivity of polymeric gaskets increases markedly after their treatment by a pulsating field. In this case, the heat conductivity of the gaskets increases throughout the range of change in the magnetic-field strength; this effect manifests itself most pronouncedly in the region where the magnetic-field strength is low and at a low concentration of a filler.

CONCLUSIONS

1. The results of treatment of thin-layer polymeric materials containing a ferromagnetic disperse filler by a magnetic field show that the heat conductivity of these materials increases depending on the magnetic-field strength, the concentration and dispersion of the filler, and the filler nature.

2. It was shown that the introduction of multicomponent fillers into thin-layer polymeric materials treated by a magnetic field makes it possible to increase their heat conductivity.

3. It has been established that the heat conductivity of thin-layer polymeric materials can be increased by increasing the density of packing of the filler particles under the action of a pulsating magnetic field.

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