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The study of the effect of polyoxadiazole fiber on the thermophysical properties of polymer composite materials based on phenylone C-1

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The impact of the content of heat-resistant organic arcelon fiber on the thermophysical properties of aromatic polyamide phenylone C-1 in the temperature range of 323 to 548 K is considered in the article. It has been determined that the introduction of 5–10 wt % of the filler leads to the positive effect. It contributes to the increase of coefficients of thermal conductivity and thermal diffusivity 1.5–2 and 1.8–2.9 times respectively. It has been shown that with the same content of the filler, we can observe the reduction of specific heat discontinuity and temperature coefficient of entropy by 40–65 % and 23–65 % respectively in the comparison with phenylone. This is due to the interaction of the filler with a polymer matrix: structure formation at the "polymer-filler" interface by straightening and aggregation of the part of phenylone macromolecules in the interfacial layer.

Keywords: fibrous polymer composite materials, polyamide phenylone, organic fiber, arcelon, heat capacity, thermal conductivity, thermaldiffusivity.

Рассмотрено влияние содержания термостойкого органического волокна арселон на теплофизические свойства ароматического полиамида фенилон марки С-1 в интервале температур 323–548 К. Установлено, что введение 5–10 масс % наполнителя приводит к положительному эффекту: способствует увеличению коэффициентов тепло- и температуропроводности в 1,5–2 и 1,8–2,9 раза соответственно. Показано, что при таком содержании наполнителя наблюдается уменьшение скачка удельной теплоемкости и температурного коэффициента энтропии на 40–65 и 23–65 % соответственно, в сравнении с фенилоном, что обусловлено взаимодействием наполнителя с полимерной матрицей: структурообразовании на границе раздела фаз "полимер-наполнитель" за счет в ыпрямления и агрегации части макромолекул фенилона в межфазном слое.

Дослідження впливу поліоксидіазольного волокна на теплофізичні характеристики органопластиків на основі фенілону С-1. *О.І.Буря, А.-М.В.Томіна.*

Розглянуто вплив вмісту термостійкого органічного волокна арселон на теплофізичні властивості ароматичного поліаміду фенілон марки С-1 в інтервалі температур 323–548 К. Встановлено, що введення 5–10 мас. % наповнювача призводить до позитивного ефекту: сприяє збільшенню коефіцієнтів тепло- і температуропровідності у 1,5–2 і 1,8–2,9 рази відповідно. Показано, що при такому вмісті наповнювача спостерігається зменшення стрибка питомої теплоємності і температурного коефіцієнта ентропії на 40–65 і 23–65 % відповідно, у порівнянні з вихідним матеріалом, що обумовлено взаємодією наповнювача з полімерною матрицею: структурування віяжучого на границі розподілу фаз "полімер-наповнювач" за рахунок випрямлення і агрегації частини макромолекул фенілону у міжфазному шарі.

1. Introduction

The enterprises of agricultural, automobile and metallurgical industries are interested in the durability and reliability of tribosystems working in the difficult operating conditions [1, 2]. The using of antifriction polymer composite materials (PCM) reinforced with organic fibers (OF) allows to provide high stability of friction units of machines and mechanisms, decrease the spending on the repair and maintenance of them, improve ecological situation (the ability to work without lubrication that pollutes environment in the case of leakage of the friction unit) [3, 4].

The study of thermodynamic characteristics (heat capacity, thermal conductivity, and thermal diffusivity) of PCM of antifriction purpose in a wide temperature range (323–548 K) is one of the most important tasks in projecting the products for work in the friction units of machines and mechanisms. That is because the accumulation of heat in the friction area of movable joints under the influence of mechanical loads is one of the main reasons causing the development of destruction processes in the volume of parts in a number of cases. That leads to their rapid wear and the decrease of reliability and stability of the work as a consequence [5, 6]. The purpose of the work is to study the impact of the content of arcelon fiber on the thermophysical properties (heat capacity, thermal conductivity, and thermal diffusivity) of polymer composite materials based on aromatic polyamide phenylone C-1.

2. Experimental

We used aromatic polyamide phenylone C-1 as a binder, because it surpasses most plastics in heat resistance and in the complex of physical and mechanical properties. Phenylone C-1 is a pink-colored finely dispersed powder with bulk density of 0.2 to 0.3 g/cm^3 which is intended for the manufacturing of products by the method of compression moulding [7].

Heat resistant arcelon fiber was used as filler. Its main advantages are availability and low cost of feedstock, and the ease of polymer synthesis and fiber formation, high resistance to high temperatures, fire resistance, chemical resistance, and good electrical insulating properties [8].

The preparation of polymer composite materials based on phenylone C-1 containing 5 to 20 wt % discrete (3–5 mm length) organic arcelon fiber was carried out by the method of dry mixing in the apparatus with rotating electromagnetic field (0.12 T) created by ferromagnetic particles which were magnetically separated. Polyamide phenylone C-1 should be carefully dried up before the formation. The mixtures thus obtained were formed into finished products by compression pressing.

Specific heat (C_p) of the PCM was determined on the "IT-C-400" device (Instrument-making plant, Kazakhstan, Aktyubinsk) according to the State Standard 23630.1. Three samples of 15±0.1 mm diameter and 10±0.5 mm height were used for determining C_p.

The coefficient of thermal conductivity (λ) was determined according to the State Standard 25630.2 on the "IT-λ-400" device (Instrument-making plant, Kazakhstan, Aktyubinsk). The essence of the method was in the measurements of thermal resistance of the sample while it was monotonously heated at given test temperatures. The sample under the test had the shape of a sharp disk with strictly parallel sides. Its diameter was 15±0.3 mm, its height (h, mm) satisfied the condition of $h \approx 3\lambda$ [6].

The coefficient of thermal diffusivity (a) of the materials was calculated by the formula:

$$a = \frac{\lambda}{C_p \cdot \rho},$$

where ρ, g/cm^3 is the experimental density of the sample which was determined according the State Standard 15139.

The thickness of boundary layer (Δr) of polymer composite materials was determined based on the following ratio:

$$\left(\frac{\Delta r + r}{r}\right)^3 - 1 = \nu\left(\frac{\Phi}{1 - \Phi}\right).$$

The part of the polymer (ν), which was located in the boundary layer, was calculated by the formula [9]:

$$\nu = 1 - \frac{\Delta C_{p,f}}{\Delta C_p},$$

where $\Delta C_{p,f}$ and ΔC_p are heat discontinuities for filled and unfilled polymer respectively; r is the radius of the fiber, μm; Φ is the volume content of the filler.

3. Results and discussion

The temperature dependence of specific heat capacity of phenylone C-1 and polymer composite materials on its base (Fig. 1)

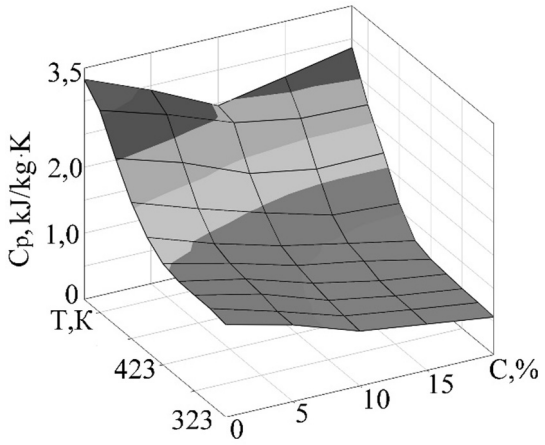

Fig. 1. Impact of the content of fiber on specific heat capacity of phenylone.

shows a linear increase in the temperature range of 323 to 423 K; this is due to energy absorption caused by increased mobility of kinetic elements of macromolecules while heating. It is known [10] that at the temperatures lower than the temperature of vitrification, the time of stress relaxation (connected with rearrangement of large sections of molecules) is so long that the rearrangement almost does not happen, and the heat absorbed from outside is spent only for increasing the vibrational energy of individual atoms of macromolecules. An intensive growth of specific heat capacity is observed at the temperatures higher than 423 K in the area of transition of the binder and polymer composite materials from glassy to highly elastic state. Such a character of the curves is explained by segmental mobility of macromolecules. At high temperatures (548 K), an intensive growth of heat capacity is observed for PCM containing 15–20 wt % of the filler. It is connected with loosening of polymer molecular organization in boundary layers. As a result, a part of functional groups of the polymer is released from molecular boundaries; they become more mobile, and the amount of conformational transformations increases [11].

One of the important thermophysical properties of PCM is heat discontinuity (ΔC_p) in the area of phase transitions of the composites. Its value is a semi-quantitative measure regarding the content of boundary layers in the filled system. It is clear from the data on Fig. 2 that the introduction of 5–10 wt % of the fiber reduces this content by 30–40 %; this can be explained by exclusion of initial polymer macromolecules from a cooperative process of vitrification as a

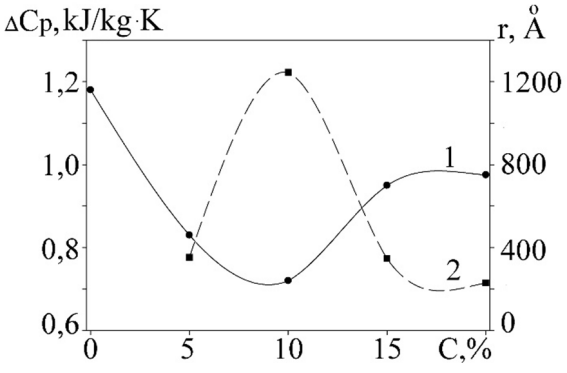

Fig. 2. Impact of the content of fiber on heat discontinuity ΔC_p (*1*) and thickness of boundary layer of polymer composite materials (*2*).

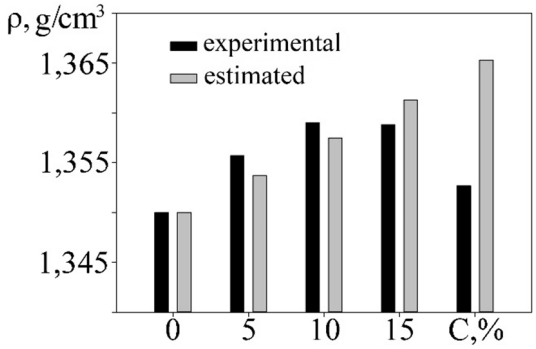

Fig. 3. Impact of the content of fiber on experimental and estimated density of phenylone.

result of their interaction with the surface of the fiber: a part of phenylone macromolecules makes their own boundary layer near the fiber surface where their mobility is much lower [12]. With further increase of the arcelon content up to 20 wt %, we can observe the boundary layer's growth connected with the development of the loosening processes in the structure of PCM on the "binder-fiber". From one hand, these findings can be confirmed by the fact that the thickness of the boundary layer with 15–20 wt % of arcelon is 3.6–5.4 times lower in comparison with the PCM reinforced with 5–10 wt % of the fiber. From the other hand, estimated density of polymer composite materials containing 15–20 wt % of the fiber is higher than the experimental one (Fig. 3).

As to thermal conductivity coefficient, it is clear from Fig. 4 that the introduction of 5–10 wt % of the fiber into the initial polymer contributes to its increase 1.5–2 times. It indicates the formation of a more ordered structure with less defectiveness in the interfacial layer: the mobility of macromolecules is limited. These results are supported by the fact that the introduction of the

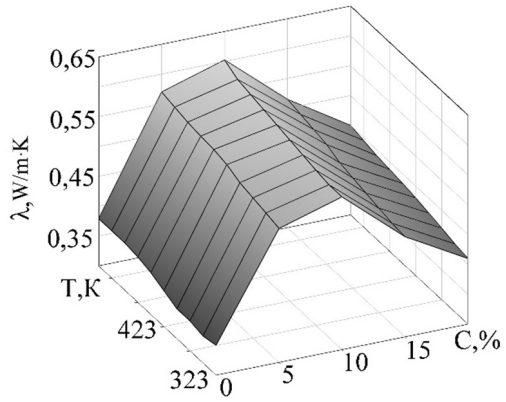

Fig. 4. Impact of the content of fiber on specific thermal conductivity of phenylone.

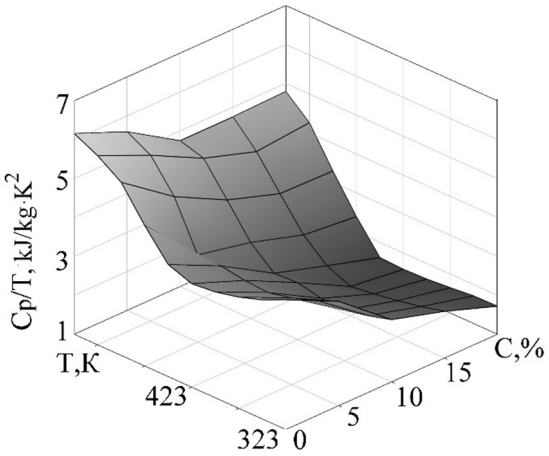

Fig. 5. Impact of the content of fiber on phenylone thermal coefficient of entropy.

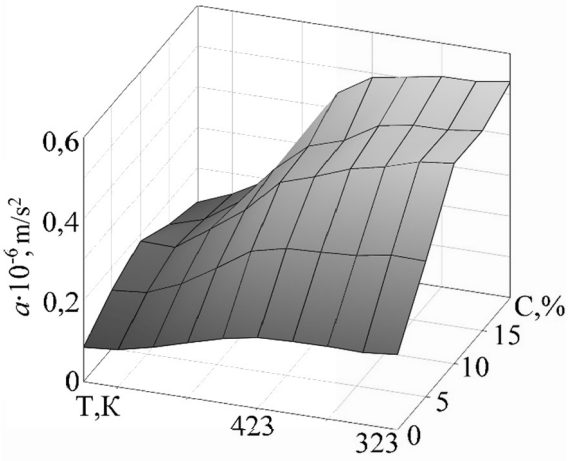

Fig. 6. Impact of the content of fiber on thermal diffusivity of phenylone.

fiber in the polymer matrix causes the reduction of thermal coefficient of entropy (C_p/T) (Fig. 5) by 23–60 % which characterizes the mobility of the macromolecules' elements of the binder [13].

With regard to the thermal diffusivity coefficient, it should be noted that with the increasing of the fiber content it increases 1.8–2.9 times in the temperature range of 323–423 K (Fig. 6); this is caused by the decrease of specific heat capacity of the polymer composite materials.

4. Conclusion

The results of the researches on the developed polymer composite materials show that the reinforcement of aromatic polyamide with organic arcelon fiber leads to a positive effect. It helps to increase coefficients of thermal conductivity and thermal diffusivity 1.5–2 and 1.8–2.9 times, respectively. It is determined that organoplastic which contains 10 wt % of the filler has an optimal complex of thermophysical properties. It allows recommending it for using in the friction units of machines and mechanisms.

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