

**STUDY ON THE PHYSICAL AND MECHANICAL  
PROPERTIES OF COMPOSITES BASED ON POLYIMIDE  
AND POLYCARBONATE**

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*Effect of the content of a polycarbonate filler on the deformation and stress of a composite material based on polyimide is studied. Mathematical models describing the main features of deformation processes of the material are proposed.*

**Introduction**

The use of some polymers of specific structure in modern production and conditions, including extreme cases (nuclear industry, space investigations, etc.), is of great interest. As is known, a strong influence on polymer composite materials is exerted by temperature, mechanical loads, etc. It is the resistance of polymers to these actions that frequently determines the spectrum of its practical application [1-3].

Upon introduction of fillers in polymer materials, their structure and physical, chemical, and thermal characteristics change considerably. Polymer composite materials on the basis of disperse fillers, possessing a specific complex of operational properties, firmly occupy their niche among other structural materials [4-6].

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## Experimental Method and Materials

New composite materials on the basis of the thermally stable polyimid (PI) and ultra-high-strength polycarbonate (PC) have been synthesized.

The method of their manufacturing is as follows.

1. 4.0 g (0.01 mole) of oxy-4,4-dianiline (4,4-diamino-diphenylsulphoxide) and 5.48 g (0.01 mole) of an ABimid varnish are placed into a three-neck flask and poured over by 12 ml of m-cresol.

2. The reaction blend is mixed in a flask under uniform heating for 5 h at a rate of 30°/h up to 170°C to produce a viscous solution.

3. The solution is diluted to 7% and supplied with a batch of filler.

4. To obtain a homogeneous blend, the solution is mixed for 2 h at 170°C, uniformly poured on a glass substrate, and rolled out in the form of a film of required size.

5. The film is dried up in a muffle furnace at 100°C.

The physical parameters were measured on a PMY-0.05-1 unit at a speed of moving clamps  $36.09 \pm 0.05$  mm/min. The stress  $\sigma$  (up to the ultimate strength of the material) as a function of relative elongation  $\varepsilon$  of polymer films in uniaxial tension at room temperature ( $20 \pm 2$ )°C was determined. The resulting data were used in constructing  $\sigma(\varepsilon)$  relations.

## Discussion of the Results

We investigated the relation between the stress and relative elongation for unirradiated PI + PC composite material of various concentrations. It was found that, upon introduction of 1 wt.% PC, the strain and strength increased 2.4 and 1.9 times, respectively. An addition of 2 wt.% PC reduced the strength by 33% and increased the strain by 65%, while polyimid became reinforced with polycarbonate, which is explained by particular features of the meshed matrix of PI on the one hand and by the high rigidity of the PC chain on the other hand. In manufacturing a composite material, PI is mixed with PC, and filler particles fill pores of the matrix. A simultaneous and uniform heating of the mass to 170°C favors the cross-linking of PC radicals with PI macromolecules.

To describe the physicomechanical properties of the materials, an exponential model is suggested. Within the framework of this model, the variation in elongation is given in the form

$$dl = l d\sigma / \sigma_0,$$

where  $l$  is the length of a specimen,  $\sigma$  is stress, and  $\sigma_0$  is the generalized modulus of strength.

Integrating the function  $l$  from  $l_0$  to  $l$  and the argument  $\sigma$  from 0 to  $\sigma$ , and taking into account that  $\varepsilon = \Delta l / l$ , we have

$$\varepsilon = \exp\left(\frac{\sigma}{\sigma_0}\right) - 1, \quad (1)$$

or

$$\sigma = \sigma_0 \ln(\varepsilon + 1). \quad (2)$$

Here,  $\sigma_0$  is the stress at which the value of  $\varepsilon + 1$  increases  $e$  times.

Expanding expression (1) into a series, we obtain

$$\varepsilon = \frac{\sigma}{\sigma_0} + \frac{\sigma^2}{2!\sigma_0^2} + \frac{\sigma^3}{3!\sigma_0^3} + \dots \quad (3)$$

At  $\sigma \ll \sigma_0$ , relation (3) transforms into Hooke's law.

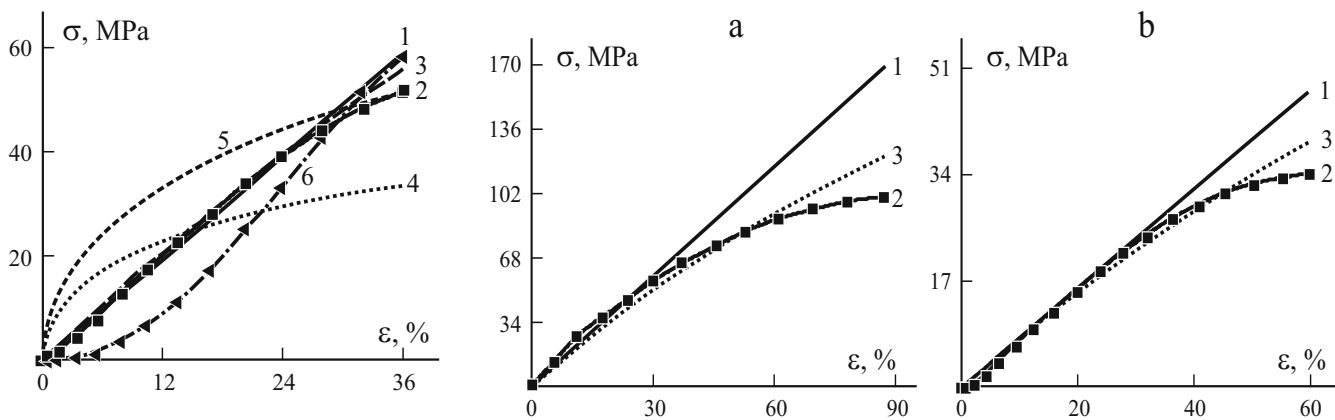


Fig. 1. Stress  $\sigma$  as a function of relative elongation  $\varepsilon$  for an unirradiated PI: 1 — Hooke's law, 2 — experiment, 3 — exponential model, 4 and 5 — exponentially quadratic model ( $\sigma_0 = \sigma_{\text{aver}}$  and  $\sigma_0 = \sigma_{\text{max}}$ , respectively), and 6 — parabolic model.

Fig. 2. Stress  $\sigma$  as a function of relative elongation  $\varepsilon$  of unirradiated PI + 1 wt.% PC (a) and PI + 2 wt.% PC (b) composite materials: 1 — Hooke's law, 2 — experiment, and 3 — calculation.

As follows from Eq. (3), the first term of the series describes the behavior of material in the elastic region, while the second and remaining ones — in its nonlinear part (plastic deformation). Further, in a similar way, we can deduce the relation between the strain  $\varepsilon$  and stress  $\sigma$  for exponentially quadratic and parabolic models can be deduced:

$$\varepsilon = \exp\left(\frac{\sigma^2}{E_1^2}\right) - 1, \quad (4)$$

$$\varepsilon = \frac{\sigma^2}{E_2^2}. \quad (5)$$

Figure 1 shows the graphs of  $\sigma(\varepsilon)$  for an unirradiated polyimide. It is clearly seen that the experimental data are much better described by the exponential model.

The exponential model was used to calculate the  $\sigma(\varepsilon)$  relationships for unirradiated composite materials (Fig. 2) with different concentrations of PC. As follows from the calculations, for a composite material with a polycarbonate filler, an increase in the concentration leads to a decrease in  $\sigma_{\text{aver}}$ . At a 1 wt.% PC, the deviation of the curve of Hooke's law from experiment is 68%, while at 2 wt.% PC, it makes 38%.

Further, we infrared (IR) spectroscopic investigations of the specimens were performed. The spectral analysis showed that 1 wt.% PC in polyimide two- to fivefold increased the intensity of the spectrum; in this case, the bandwidth grew. The most informative lines lay in the intervals of 500-1100  $\text{cm}^{-1}$  and 1700-3500  $\text{cm}^{-1}$  (see Table 1).

In the first interval, most noticeably expressed was the content of overtones of benzene rings of PI, aliphatic groups of PCs, replaced benzene rings of PI, associated carbonyl groups of PI and PC, and ester groups of PC. Characteristic of the second interval were the associated carbonyl and carbamide groups of PI, lactone and ester parts of PC, and associated groups of PI ( $=\text{N}-\text{H}$  and  $-\text{NH}_2$ ).

As seen from the data of Table 1, the introduction of PC increased the concentrations of chemical compounds (overtones of benzene rings of PI, aliphatic groups of PC, replaced benzene rings of PI, associated carbonyl groups of PI and PC, ester groups of PC, lactone groups of PC, associated carboxyl groups of PI, associated carboxyl groups of PI, and associated  $=\text{N}-\text{H}$  and  $-\text{NH}_2$  PI groups), which led to the cross-linking of PC radicals with PI macromolecules, thus improving the mechanical properties of the composite examined.

TABLE 1. Variation in the Intensity of IR Spectrum Bands of Wavelengths of a Composition with 1 wt.% PC

Chemical compound	Frequency range, cm <sup>-1</sup>	Increase in intensity, times
Overtones of benzene rings of PI	443.1	2
	490.9	2.8
	526.8	3.6
	603.6	3.4
	660	3.5
Aliphatic groups of PC	726	3.3
Replaced benzene rings of PI	797.1	3.3
	835.8	3.7
	871.7	3.7
	947.6	4
Associated carbonyl groups of PI and PC	1061	4.9
Ester groups of PC	1107.5	2
Lactone groups of PC	1772.2	2.5
Associated carboxyl groups of PI	2952.6	7.75
Associated carboxyl groups of PI	3052.5	6.7
Associated =N—H and —NH <sub>2</sub> groups of PI	3361.5 and 3466.3	3.8

## Conclusions

1. It is found that significant changes in the mechanical properties of composite film materials on the basis of polyimide and polycarbonate depend on the concentration of filler and are caused by the salient features of their internal structure.

2. Based on consideration of the balance equation in uniaxial loading of materials, several models are suggested. The best agreement with experiments was found in the case of the exponential model.

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