Investigation of Mechanical Properties of Polyimide-Polyethyl-eneterephthalate System

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Abstract. The study of the physico-mechanical properties of new composite materials based on polyimide (PI) and polyethyleneterephthalate (PET) was carried out. Dependences of σ from ε for different concentrations of the second component and irradiation doses were measured. The experimental data are described satisfactorily by the exponential cascade-probabilistic model.

Keywords: mechanical properties, composite material, polyimide, polyethyleneterephthalate, strain, irradiation, plasma particle flux, strength.

1. Introduction

Currently, much attention is paid to the development of new thin-film materials [1]. Examples of their use are elements of integrated circuits in modern micro- and nanoelectronics, coatings (protective, hardening, semi-transparent, dielectric, magnetic, and so on). Depending on the function of material its thickness varies widely – from a few angstroms to several tens of micrometers [2].

Due to the high requirements of technology, modification of polymers has become predominated, because it allows creating new compositions for special purposes, which form a system with the specified properties: specific electrical conductivity, strength, ductility, resistance to radiation, high and low temperatures [3]. The multifunctional material which combines a number of useful consumer properties is obtained by introducing different active compounds into the polymer matrix [4].

Studying the influence of a certain type of filler on physico-mechanical properties of polymeric composite materials (PCM) is not only of scientific but also of practical interest [5]. Introduction of additives alters the structure and properties of the system. The interaction of particles at the polymer-filler interface is the basis of the mechanism of modification of PCM characteristics. Strength and plastic properties of polymer composites are significantly affected by the fillers used and their concentrations. Irradiation of different systems by a stream of plasma particles, accelerated ions and electrons leads to changing their characteristics.

Polymer composites consist of two main parts: a binder polymer and a reinforcing filler. In polymer mixtures hard-chain polymers stimulate the orientation of macromolecules with a flexible chain or amorphous flexible chain polymers lead to disordering of crystalline polymers and create new possibilities for controlling their properties. Due to the heat resistance, polyimide composite materials are used as structural materials in main branches of industry. As it is known, polyimides (PI) are cyclochain heterocyclic polymers containing macromolecules of cyclic imide groups in the main or side chains. PI have high thermal stability, extremely high resistance to effect of plasma flows and radiation, as well as high strength and flexibility. Polyethylene terephthalate was selected as the filler.

Polyethylene terephthalate is a polycondensate of terephthalic acid (OH)-(CO)-C6H4-(CO)-(OH) and monoethyleneglycol (OH)-C2H4-(OH). During polycondensation, linear molecule of polyethylene terephthalate [-O-(CH2)2-O-(CO)-C6H4-(CO)-]n and water are formed. Polyethylene terephthalate is durable, hard and light material.

2. Experimental

Dependence of stress σ on deformation ε of new composite materials (based on PI and PET) (irradiated and non-irradiated) under uniaxial stress for several concentrations of the second component (polyethylene terephthalate - PET) was studied.

Composite films were prepared according to the scheme shown in Fig.1. Current technologies [1] were used for preparation of composites as a mixture of PI+PET with the following concentra-tions of filler: 0.5; 2 and 5 wt.%.

Mechanical testing of the materials was carried out on a tensile testing machine of RMU-0.05-1 type with the rate of clamps moving of 36.09 ± 0.05 mm/min. Capture moving associated with measuring does not exceed 0.1 mm. Tests were conducted as uniaxial stretching with a special reverser at a constant temperature (20 ± 2) °C and relative humidity (45 ± 5)%. Tensile testing machine was equipped with appropriate software – standard Windows application.

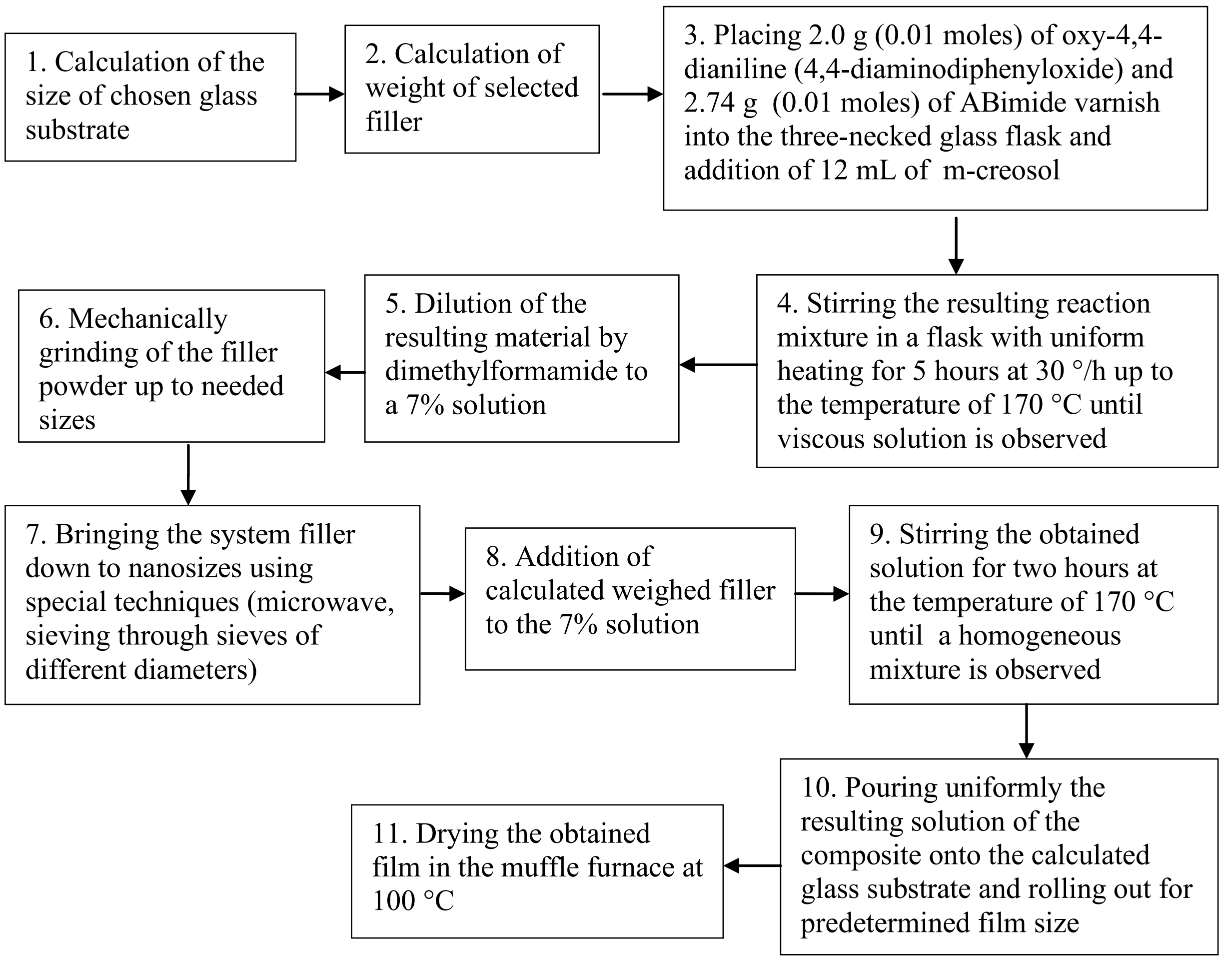

Figure 1. Technological scheme of the composite based on polyimide

Samples of the films were fixed with special clamps. Workspace was 50 mm (length), 5 mm (width), and thickness - 35 microns for polyimide and (40 ÷ 75) mm for composite materials.
Irradiation of samples was carried out in the air on ELU-6 electronic linear accelerator with the energy of the incident particle of 2 MeV to the absorbed dose (D) = 250 kGy.

3. Results and discussions

Introduction of 0.5 wt.% of PET increases the strength of the material by 37 % and elongation by 100% compared with the pure polyimide. Improvement of the mechanical properties of composite materials with a filler of PET is due to the fact that they were obtained by stirring the polyethylene terephthalate and polyimide, and filler particles fill the pores of the matrix fixing the molecules of lavsan and polyimide i.e. structuring of polyimide chains by plastic skeleton of polyethylene terephthalate occurs. Simultaneous and uniform heating to 170 °C promotes cross-linking of the radicals of polyethylene terephthalate with polyimide macromolecules. Increase in concentration of filler C and stress σ increases the deformation ε. So for C = 5 wt.% and σ = 70 MPa, ε was increased 2 times as compared with C = 0.5 wt.% (Table 1).

Table 1. Dependence of the relative lengthening on the concentration of the second component

σ =10 [MPa]		σ =30 [MPa]	σ =50 [MPa]	σ =60 [MPa]	σ =70 [MPa]
C [wt.%]	ε [%]	ε [%]	ε [%]	ε [%]	ε [%]
0	6	17.9	34.5	-	-
0.5	7.5	20.2	28.1	47.2	75.1
2	6.8	18.7	27	51.6	80.8
5	8	22.8	32.6	80.8	204.4

Effect of electron irradiation of 250 kGy on the composite (filled with 0.5 wt.% PET) increases strength by 17 % and relative extension by 23 % in relation to the original value of the pure polyimide. In comparison with non-irradiated polyimide, the impact of these factors leads to improvement of the mechanical properties of composite materials. This is explained by additional polymerization of the polymer matrix and cross linking of macromolecules that occurs during irradiation. Filler as lavsan forms a homogeneous composite with polyimide and enhances its mechanical properties.

Exponential model was used to describe the physico-mechanical properties based on the balance equation within the cascade-probabilistic method under uniaxial stress of materials. In particular, the dependence of the deformation (ε) of the stress (σ) for the case of the exponential model is represented as [6]:

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

or, after conversion:

$$\sigma = \sigma_0 * \ln(\varepsilon+1),$$

where σ_0 is generalized strength module.

Fig. 2 shows the stress-elongation dependence for non-irradiated (a) and irradiated (b) composite samples for C = 0.5 wt.% and D = 0 and 250 kGy.

Comparing the theoretical (calculated by the exponential model, curve 3) and experimental (curve 2) curves, a good agreement can be observed. The same figure shows also the theoretical curve calculated by Hooke's law (curve 1). It can be seen that at maximum elongation Hooke curve odds with experiment by 50 %. For irradiated composite, the difference reaches 68 %.

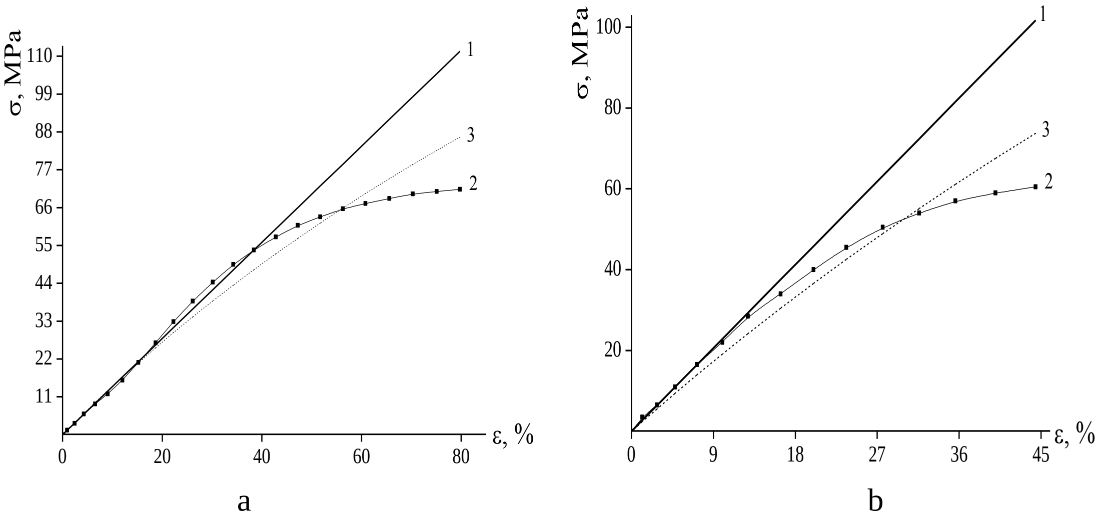

Figure 2. Dependence of the stress on the relative elongation for the composite material of PIAB + 0.5 wt.% PET: a) D = 0; b) D = 250 kHr
1 – Hooke's law, 2 – experiment, 3 – calculation by cascade-probabilistic model

4. Conclusion

1. It was found that the mechanical properties of composite film materials based on polyimide and polyethylene terephthalate before and after irradiation depend on the concentration of the filler and are due to the features of internal structure.
2. It was shown that the exponential model gives the best agreement with experiment. At the same time, calculation according to Hooke's law at a maximum ε overstates σ by 50-70 %.

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