# Study of deformation dependence on time in polyethylene terephthalate for different static loads and irradiation doses

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**Abstract.** Complex experiments were conducted on deformation dependence on time for different static loads and irradiation doses in polyethylene terephthalate. Curves of time (t) dependence of deformation (ε) show a significant change in the behavior of the material after irradiation. The obtained dependence curves of ε on t for both non-irradiated and irradiated materials are satisfactorily described by cascade-probability model.

## 1. Introduction

Widespread use of polymeric materials leads to steadily increased volumes of their production. World production of plastics increases two times every fifteen years, and by 2010 it had reached 250 mln. tns. Moreover, the fastest growing market today is polyethylene terephthalate (PET, PETP, polyester). Polyethylene terephthalate is a polymer that has revolutionized the world of packaging, radically changing the situation in the world market in the field of production [1–3].

Materials consisting of PET were developed in the early 1940s and has since proven its versatility of application in various areas of life: in light industry, food industry, and machine-instrument making, mechanical engineering, medicine and pharmaceuticals. In addition, PET is an excellent material for the manufacture of various types of films and containers. High consumer properties of PET containers have provided a rapid growth in the production of packaging for food and beverage products. PET has good heat resistance in the temperature range from –40 °C to +200 °C. A small water absorption provides high stability of properties and equipment sizes. Products made of PET have good mechanical properties, resistant to impact and cracking. PET is stable to diluted acids, oils, alcohols, mineral salts and organic compounds but not to strong alkalis and some solvents. It minimally adsorbs odors and exhibits good gas barrier properties [4–7]. At the same time, the problem of regulations of properties is topical. One of the methods of improving the characteristics of the material is exposure to radiation. Many irradiation types affect the properties of polymeric materials, resulting in a change in their structure depending on various factors [8–10]. Investigation of the effect of charged particles on the properties of polymers is very

relevant and allows directed modification of their properties. This work is devoted to the study of deformation dependence on time in polyethylene terephthalate for different static loads and irradiation doses.

## 2. Methodology

Industrial polyethylene terephthalate 90-μm thick was selected as the test material. The film samples were cut using a special device. The length of the material to be tested was 7 cm and the working part was 5 cm (2 cm of polymer sample were fixed in the clamps), the width was 0.5 cm.

In order to carry out studies, the maximum load at which rupture of the tested polymer occurs had been previously determined using special cargo. For this lavsan material it was 13.5 MPa. Then the strain constituting a certain part of the limit strain was calculated. After that, the sample was mounted in the clamps. The dependence of ε on t was recorded. The timing of the test sample on uniaxial tensile static load was about 50 sec. The data were recorded on a video camera. After that, all the material was processed. The error was 0.1%.

The studies of the dependence of deformation on strain of both non-irradiated and irradiated materials were performed using a modified tensile device based on RU-50 with crosshead speed of 12 cm/min.

Irradiation of samples was carried out using ELU-6 linear electron accelerator with energy of 2 MeV in air. The irradiation dose was equal to 50 and 100 kGy. The samples of the films were placed at a distance of 40 cm from the output window of the accelerator. The material temperature was 23 °C and the relative humidity was 55%.

## 3. Results and discussion

Figures 1 and 2 show the experimental results on the dependences of deformation ε on time t at different values of static strain: $\sigma_1 = 7$; $\sigma_2 = 10$; $\sigma_3 = 11$; $\sigma_4 = 12$ and $\sigma_5 = 14$ MPa, and the irradiation doses of 0, 50 and 100 kGy.

It was found that the relative elongation of the material depends significantly on the static load, reaching more than 500% of the initial value and becomes a constant over time (Figure 1, curves 1, 3, 5, 7, 9; Figure 2, curves 1, 3, 5).

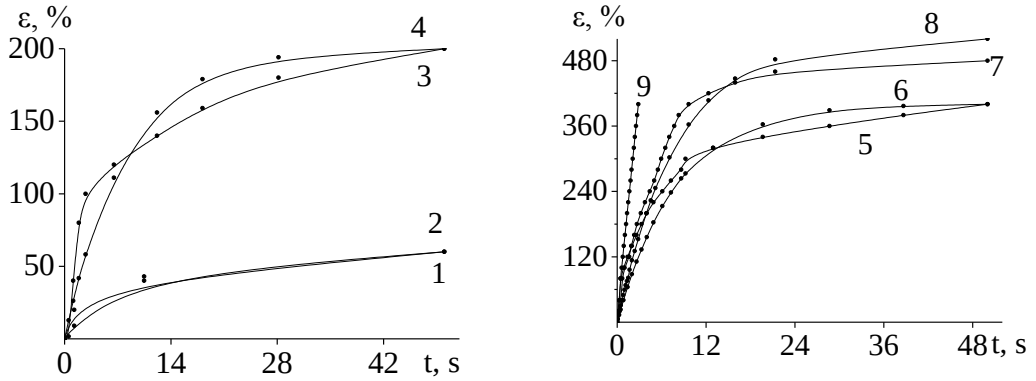


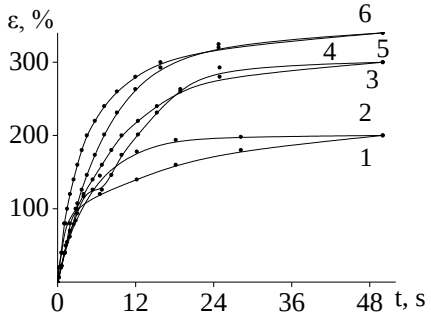

**Figure 1.** Dependence of deformation on time for non-irradiated polyethylene terephthalate at different static loads experiment at σ = 7, 10, 11, 12, 14 MPa (1, 3, 5, 7, 9); calculation at σ =7, 10, 11, 12 MPa (2, 4, 6, 8)

Calculation of the dependence of ε ***on*** $t$ was carried out using the cascade-probability model according to the formula: $\varepsilon = \varepsilon_0[1-\exp(t/t_0)]$. For this experiment, $\varepsilon_0$ is the maximum elongation, $t_0$ is the time at which $|\varepsilon/\varepsilon_0 - 1|$ decreases by a factor $e$. Table 1 shows the values of $t_0$ and $\varepsilon_0$ for different values of σ.

**Table 1.** Dependence of $\varepsilon_0$ and $t_0$ values on σ

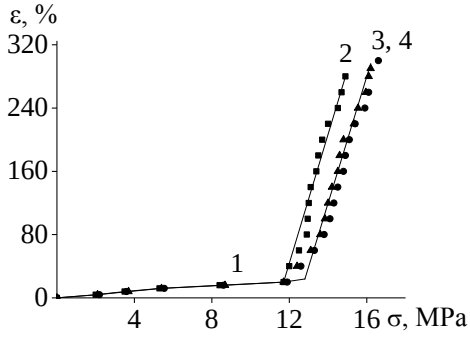
| σ, (MPa) | 7 | 10 | 11 | 12 |
|---|---|---|---|---|
| $\varepsilon_0$, (%) | 60 | 200 | 360 | 520 |
| $t_0$, (s) | 6 | 8 | 10 | 12 |

As seen from the table, increase in σ value leads to significant increase in $\varepsilon_0$ and $t_0$. Figure 2 shows that with increasing radiation dose (D), deformation increases sharply at first, and then gradually reaches saturation. Dependence of $\varepsilon_0$ and $t_0$ parameters on D is shown in Table 2. With increasing σ, Dε increases. According to the results obtained, electron irradiation alters ε by more than 100%.




1 – non-irradiated sample; 3 – 50;
5 – 100 kGy, – experiment;
2 – non-irradiated sample, 4 – 50;
6 – 100 kGy, – calculation

**Figure 2.** Dependence of deformation on time for PET for different doses of electron irradiation at static load of σ = 11 MPa




square – non-irradiated sample; circle – 50;
triangle – 100 kGy, – experiment;
1 – non-irradiated sample, 2– 50;
3 – 100 kGy, – calculation

**Figure 3.** Dependence of deformation on mechanical strain of irradiated and non-irradiated polyethylene terephthalate

**Table 2.** Dependence of $\varepsilon_0$ and $t_0$ values on the irradiation dose

| D, (kGy) | 0 | 50 | 100 |
|---|---|---|---|
| $\varepsilon_0$, (%) | 200 | 300 | 340 |
| $t_0$, (s) | 6 | 8 | 10 |

After irradiation by the doses of 50 and 100 kGy, the samples of material gain significant flexibility and begin to tear at deformations and strains greater than those before irradiation. Thus, an increase in tensile strength by 10 and 15 % is observed compared with non-irradiated material (Figure 3, curves 3 and 4). In the strain range of 12–16 MPa, electron irradiation results in a substantial reduction of the deformation (80 %). Lavsan films are characterized by good elasticity, and it is partially reversible. The material contains regularly spaced polar groups, whose function is to enhance the intermolecular interactions and the formation of the material stiffness. According to Figure 3, the experimental curves are satisfactorily described by the linear model [8]. In this case, in the range σ = 0–12 MPa, the experimental data for the non-

irradiated and irradiated samples (curve 1) coincide. The change in the angle of inclination of the curve at $\sigma = 12$ MPa is due to the transition from the elastic region of deformation to catastrophic tear of the material. The reduced material strength and increased elongation indicate a significant influence of radiation defects on the structure and mechanical properties of lavsan.

## 4. Conclusions

1. Complex experiments were conducted on the deformation dependence on time for different static loads and irradiation doses: $\sigma_1 = 7$; $\sigma_2 = 10$; $\sigma_3 = 11$; $\sigma_4 = 12$ and $\sigma_5 = 14$ MPa. It was found that the deformation of the material depends strongly on time and static load.
2. Irradiation of PET samples results in significant improvement in the flexibility, and a significant increase in strain (more than 100% compared with non-irradiated material), which is associated with degradation of the polymer chains. However, strength is virtually unchanged.
3. Experimental dependences of $\varepsilon$ on $t$ and $\varepsilon$ on $\sigma$ for both non-irradiated and irradiated materials are satisfactorily described by cascade-probability and linear models.

## Acknowledgments

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