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Effect of anomalous broadening in uniaxial stretching of thin polyethylene films

A I Kupchishin[1,2], M N Niyazov[1], V M Lisitsyn[3], BG Taipova[1], N A Voronova[1] and A T Abdukhairova[1]

[1]Abay Kazakh National Pedagogical University, 13 Dostyk Ave., Almaty, 050000, Kazakhstan
[2]Al-Farabi Kazakh National University, 71 al-Farabi Ave., Almaty, 050040, Kazakhstan
[3]Tomsk National Research Polytechnical University, 30 Lenin Ave., 634050, Tomsk, Russia

E-mail: ankupchishin@mail.ru

Abstract. Experimental studies have been carried out on the dependence of the deformation of the width ε_a on deformation of the length ε_l of unirradiated and irradiated polyethylene (PE) film. It is found that these quantities depend essentially on the rate of loading. An anomalous change in the deformation along the samples length was observed in the stress range of 9-13 MPa. Irradiation with electrons leads to a decrease in deformation and has little effect on the anomalous broadening.

1. Introduction

As is known, polyethylene (PE) is one of the most widely distributed materials in the world [1, 2]. The monomer of polyethylene is a simple compound consisting of two carbon atoms and four hydrogen atoms. It is estimated that now the population of the planet consumes up to one trillion plastic bags per year [3]. Almost eighty percent of consumption falls on Western Europe and the United States. A large number of different polymers used in everyday life has different chemical structures, and therefore, various mechanical, electrical, optical and other properties [4]. The mechanical properties of PE largely depend on the crystallinity and molecular weight [5, 6]. This polymer is also known for its lower density compared to water (0.92-0.96 g/cm^{-3}). Deformation under uniaxial strain is one of many ways to test polymers for mechanical properties. It provides a simple and effective way to study the reaction of polymer materials to the load [7, 8]. Mechanical properties are often used to predict the behavior of materials [9, 10]. We observed an anomalous relative change in the width of the polyethylene film as a function of the relative elongation of ε_l at various static loads with the formation of globules along the length of the stretch film. The influence of electron irradiation on the deformation of the PE width has been studied.

2. Experimental

An installation has been designed and made providing the possibility of measuring the parameters of length l and width a at various static loads and their change through time. An industrial PE of 110 μm thickness was chosen as the material to be studied. The length of the samples of the test material was

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70 mm, the working part was 50 mm, the width was 5 mm. The limiting load σ_{max} was determined experimentally and the dependence of the deformation of the width ε_a on deformation of length ε_l was studied. For the material studied, the value of σ_{max} is 12-14 MPa. The samples were gradually subjected to strain and data were collected at regular intervals, which were then processed. The time of each experiment was 2 minutes. Also, experiments were conducted to determine the dependence of the relative elongation ε for time *t*. The temperature of the material during the studies was 23°C. Irradiation of the samples by electrons was carried out on ELA-6 linear accelerator with an energy of 2 MeV in the air. Samples for irradiation were placed at the distance of 40 cm from the exit window of the accelerator. The magnitude of the beam current was 0.3 mA/cm^{-2}, the irradiation dose – 700 kGy.

3. Research results

Photos of the stepwise deformation of the unirradiated polyethylene film as a function of time at σ=13 MPa are shown in figure 1. The center of the sample in the figure coincides with its center.

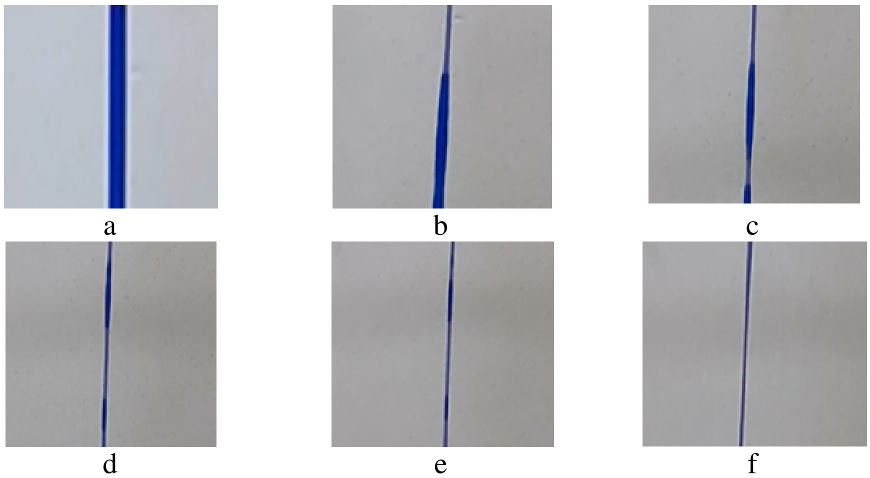


Figure 1. Photos of deformation of polyethylene film upon time: a – 20; b – 40; c – 60; d – 80; e – 100; f – 120 s.

Analyzing the figures, we can conclude that globules begin to appear already in the first minute of deformation. Irradiation of polyethylene film by electrons has a little effect on the anomalous broadening. This behavior of the material is due to the breaking of the chains and their cross-linking, as well as the rupture of macromolecules in these places. In the photos c, d and e of figure 1, the effect and number of globules are clearly visible. The results of the studies are presented in tables 1 and 2. From the analysis of the dependences of ε_a on ε_l, it follows that the change in the elongation of the material affects significantly the reduction in the width of the polyethylene samples. However, this occurs unevenly over the entire length of the test material. From the table, we can conclude that ε_a reaches the highest values in the middle of the sample, where the so-called "neck" is formed. The reason for this is a complex interaction between polymer chains and cantilever fixing of films on both sides, closer to which the width and material thickness parameters vary slightly.

At σ=8 MPa, the length deformation increases monotonically, reaching a maximum. And the deformation of the width, in addition to all that has been said, also slowly decreases, acquiring the maximum values (regardless of the load) in the middle of the samples. In the stress range of σ=10-13 MPa: so-called "globules" appear on all sections of the film during stretching, that is, an anomalous broadening effect (due to the delay in straightening out a part of the chaotically located chains and their branching). It depends largely on the magnitude of the static load. Moreover, the appearance of globules in the polymer working region is not regular. Table 2 shows the results of the dependence of the deformation of the width on the deformation of the length of the irradiated PE.

From the data obtained, it can be seen that irradiation of polyethylene films leads to a decrease in length deformation and slightly affects the anomalous broadening. At σ=13 MPa, the irradiated PE samples are not broken, while unirradiated PE are broken. The length deformation after irradiation decreases from 20 to 40% for various static loads (tables 1 and 2).

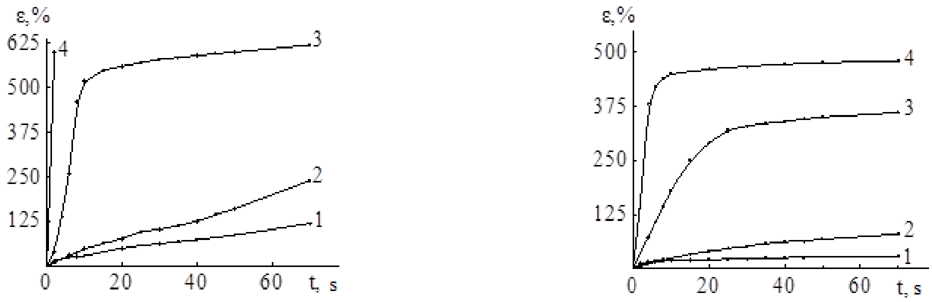
Table 1. Parameters of deformation of the length and width of samples of unirradiated PE at various static loads.

σ, (MPa)	8		10		11		13	
	ε_a,(%)	ε_l, (%)	ε_a, (%)	ε_l, (%)	ε_a, (%)	ε_l, (%)	ε_a, (%)	ε_l, (%)
	25	0	40	0	50	0	0	0
	30	11	0	22	0	57.3	75	55
	35	21.9	0	44	0	114.5	80	110
	40	26	50	52	60	135.4	0	129
	45	33	55	66	65	172	0	165
	50	44.5	60	88.8	70	231	90	222
	55	55	65	110.4	0	287.5	95	276
	55	66	65	132	0	344	95	300
	50	77	60	154	75	401	90	385.2
	45	88	0	176	70	458	0	440
	40	99	0	198	65	515.6	0	495
	35	104	50	208	60	541.3	85	519.6
	30	110	45	220	55	572.5	80	549.6
	25	120	40	238	50	620	75	595.2

Table 2. Parameters of length and width deformation of PE samples irradiated by electrons with a dose of 700 kGy at various static loads.

σ, (MPa)	8		10		11		13	
	ε_a,(%)	ε_l, (%)	ε_a, (%)	ε_l, (%)	ε_a, (%)	ε_l, (%)	ε_a, (%)	ε_l, (%)
	25	0	40	0	50	0	0	0
	30	2.7	0	7.4	0	33	75	45.85
	35	5.3	0	15	0	66.5	80	91.6
	40	6.3	50	17.5	60	78.5	0	108.3
	45	8	55	22	65	100	0	137.5
	50	10.7	60	29.7	70	134	90	185
	55	13.3	65	37	75	167	0	230
	55	16	65	44.2	80	200	0	275
	50	18.6	60	51.6	75	233	90	321
	45	21,2	0	59	70	265.7	0	366.6
	40	24	0	66.4	65	300	0	412.5
	35	25.1	50	69.7	60	314	85	433
	30	26.5	45	73.7	55	332	80	458
	25	28.7	40	80	50	359.6	75	480

Experimental studies of the dependence of the deformation ε on time t for different values of the static loads σ_1=8; σ_2=10; σ_3=11 and σ_4=13 MPa, and the radiation doses of 700 kGy are shown in figure 2. It was found that the relative elongation of the material is significantly dependent on the static load, reaching more than 600% of the initial value and with large loads (not exceeding the tensile strength) on the constant (figure 2a for the unirradiated material, curves 2 and 3; figure 2b for the dose of 700 kGy, curves 3 and 4). After irradiation with the dose of 700 kGy, the polyethylene film samples become less plastic and start tearing with less deformation than before irradiation. At the same time, an insignificant increase in the tensile strength is observed in comparison with the unirradiated material (figure 2, curves 4, right and left). In the strain range of 8–13 MPa, electron irradiation leads to the decrease in deformation (up to 40%). The PE is characterized by good elasticity, and it is partially reversible. The change in the slope of curve 4 of the left part of the figure for σ=13 MPa is associated with the transition of deformation from the elastic region to the area of catastrophic destruction of the material. The increase in the strength of the material and the decrease in the relative elongation indicate a significant effect of radiation defects on the structure and mechanical properties of polyethylene, namely, the crosslinking process takes place in the structure of the samples.



a b

Figure 2. Dependence of the deformation on time for various static loads of unirradiated (a) and irradiated (700 kGy) (b) polyethylene film. 1 – 8; 2 – 10; 3 – 11; 4 – 13 MPa.

4. Conclusion

Under certain static loads, the appearance of globules (broadenings) along the length of the material was detected. The broadening in polyethylene film depends on the rate of loading and appears on different sites. The reason for the appearance of globules is connected with the branching and uneven distribution of macromolecules. After stretching the polymer to the maximum value, the broadening disappears, and the film becomes uniformly stretched.

After irradiation with the dose of 700 kGy, the samples of the polyethylene film become less plastic and begin to tear with less deformation than before irradiation. At the same time, an insignificant increase in the tensile strength is observed in comparison with the unirradiated material because of their cross-linking, as well as the rearrangement of the macromolecules in these places. Irradiation of polyethylene film by electrons with the dose of 700 kGy does not significantly affect their anomalous behavior.

Acknowledgments

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References

[1] Liu G L, Zhu D W, Liao S J, Ren L Y, Cui J Z and Zhou W B 2009 *J. Hazard. Mater.* **172** 1424
[2] Zhao X, Zongwei Li, Yi Ch, Liyi Sh and Yongfa Zh 2007 *J. Mol. Catal.* **268** 101
[3] Kupchishin A I, Niyazov M N, Voronova N A, Kirdiashkin V I and Abdukhairova A T 2017 *IOP Conf. Series: Materials Science and Engineering* **168** 012016
[4] Sun J, Zhang Y and Zhong X 1994 *Polymer* **35** 2881
[5] Fisher G L, Lakis R E, Davis C C, Szakal C, Swadener J G, Wetteland C J and Winograd N 2006 Applied Surface Science **253** 1330

IOP Conf. Series: Journal of Physics: Conf. Series **1115** (2018) 052033 doi:10.1088/1742-6596/1115/5/052033

[6] Voronova N A, Kupchishin A I, Niyazov M N, Lisitsyn V M 2018 *Key Engineering Materials*
[7] Kupchishin A I, Taipova B G, Kupchishin A A et al. 2016 *IOP Conf. Series: Material Science and Engineering* **110** 012037
[8] Ferreira M J, Almeida M F and Freitas F 2011 *Polymer Engineering & Science* **51** 1418
[9] Zuyev V V, Uspenskaya M V and Olekhnovich A O 2010 *Physics and chemistry of polymers* (SPb.: SPbGU ITMO) p 48
[10] Sorokin S V, Terent'yev A V and Krotov Ye A 2014 *Introduction to the mechanics of a deformable solid* (SPb: SPbGMTU)