Mechanical properties of polyethylene foils

Mechanické vlastnosti polyetylénových fólií

Ľubomír KUBÍK[1*] and Stanislav ZEMAN[2]

[1] Department of Physic, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic, tel.: +421 37 6414879, fax.: +421 37 7417 003,*correspondence: Lubomir.Kubik@uniag.sk

[2] Department of Production Engineering, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic, tel.: +421 37 6414 300, fax.: +421 37 7417 003, Stanislav.Zeman@uniag.sk

Abstract

The paper deals with the evaluation of the mechanical properties of the polyethylene foils such as the stress, strain, modulus of elasticity and stress and strain in the moment of breaking. The thin foils (50 µm) which contained 91 % of polyethylene Bralen RA 2–63 and 9 % colored concentrate Maxithen were studied. Four sorts of foils were examined: Maxithen HP 1510 – white, Maxithen HP 231111 – yellow, Maxithen HP 533031 – blue and Maxithen HP 533 041 – violet. Longitudinal and transversal tensile properties were studied. The tensile behavior was monitored on the motorized test stand ANDILOG STENTOR 1000. The moduli of elasticity of longitudinal samples of polyethylene Bralen RA 2—63 foils achieved the values in the range from 222.73 MPa to 298.24 MPa and the transversal samples in the range 179.61 MPa to 270.41 MPa. The stress of longitudinal samples of polyethylene Bralen RA 2–63 foils in the moment of the rupture achieved the values in the range from 9.46 MPa to 13.33 MPa at the strain from 1.51 mm*mm^{-1} to 1.54 mm*mm^{-1} and the transversal samples in the range from 12.38 MPa to 15.54 MPa at the strain from 1.48 mm*mm^{-1} to 1.58 mm*mm^{-1}.

Keywords: polyethylene foil, stress, strain, tensile modulus of elasticity

Detailný abstrakt

Práca sa zaoberá hodnotením mechanických vlastností polyetylénových fólií, a to napätiami, deformáciami, modulmi pružnosti a napätiami a deformáciami v okamihu pretrhnutia. Tenké fólie (50 µm) obsahovali 91 % polyetylénu Bralen RA 2 – 63 a 9 % farebného koncentrátu Maxithen. Fólie sú využívané na mulčovanie v poľnohospodárstve. Boli študované štyri druhy fólií: vzorky s Maxithenom HP 1510 – biele, s Maxithenom HP 231111 – žlté, s Maxithenom HP 533031 – modré a s Maxithenom HP 533 041 – fialové. Ťahové vlastnosti boli zisťované pre pozdĺžne a priečne vystrihnuté vzorky. Správanie sa vzoriek pri ťahovom namáhaní bolo monitorované testovacím zariadením ANDILOG STENTOR 1000. U pozdĺžnych polyetylénových vzoriek fólie Bralen RA 2 – 63 boli zistené moduly pružnosti v rozsahu od 222,73 MPa do 298,24 MPa a u priečnych vzoriek v rozsahu od 179,61 MPa do 270,41 MPa. Hodnoty mechanického napätia pre pozdĺžne vzorky polyetylénu Bralen RA 2–63 v okamihu pretrhnutia vzorky boli v rozsahu od 9,46 MPa do 13,33 MPa pri zodpovedajúcich deformáciách v rozsahu od 1,51 $mm.mm^{-1}$ do 1,54 $mm*mm^{-1}$ a pre priečne vzorky v rozsahu od 12,38 MPa do 15,54 MPa pri zodpovedajúcich deformáciách od 1,51 $mm*mm^{-1}$ do 1,58 $mm*mm^{-1}$.

Introduction

Thin plastic films are used in a wide variety of applications such as packaging materials, heat shrink wrap, consumer plastic bags, and adhesive tape. The end use of a thin plastic film may require either high stretching (food wrap) or low stretching (protective coatings). Tensile modulus is a measure of a film’s resistance to stretching and therefore is an important property to correlate with end–use performance (Foreman, et al, 1997).

The great importance have polyethylene plastic foils applied in the horticulture. The plastic foils applied as mulch, affect the radiation balance of the environment by means of absorption and reflection of the light by their surface and they change of the microclimate of the cultivated plants. The color of the foils influences on the temperature of the foils and layer of the soil lying below it. The mulch modifies the microclimate by increasing soil temperature and reflectivity while decreasing soil water and nutrient loss. Black foils absorb most ultraviolet, visible and infrared wavelengths of incoming radiation. Compared to bare soil, daytime temperature approximately 5 degrees C higher at the 5–cm depth and 3 degrees C higher at the 10–cm depth. White foils reflect radiation, with soil temperature resulting in a slight decrease of –0.7 degrees C at the 10–cm depth. Blue has been shown to increase muskmelon, cucumber and summer squash yield by 20 to 30 percent over 3 years in trials at the Penn State Center for Plasticulture (Taber, 2010).

The foils evoke more favorable conditions of the growing and progression of the plants which consequence is enhancing of the harvest, quality and the realized production (Romic, et al., 2003; Ibarra–Jimenez, et al., 2006).

The best response on the application of foils have fruiting vegetables. Mechanical properties of the polyethylene foils are important for determination of suitable mulch foils to the various plants from the point of view to penetration of the plants through mulch foils. The objective of this study was to examine the tensile behaviour of various thin foil plastic materials and to measure the modulus in the linear region.

Material and Methods

Samples contained 91 % of polyethylene Bralen RA 2–63 and 9 % colored concentrate Maxithen. They were made by Plastika a.s. Nitra for mulch applications. Four sorts of foils were examined: samples with Maxithen HP 1510 – white, Maxithen HP 231111 – yellow, Maxithen HP 533031 – blue and Maxithen HP 533 041 – violet. Thickness of the samples was 50 μm. Examinations were realized by means of Standard STN EN ISO 527 – 1, 2, 3. Samples were cut in the longitudinal and transversal direction on the dimensions (150x15) mm. Ten samples of the foils were used of each sort. In this test, a load was applied along the longitudinal axis of test specimen. The applied load and the resulting elongation of specimens were measured. The process was repeated with increased load until the desired load levels were reached or the specimen breaks. The tensile behavior was monitored on the motorized test stand ANDILOG STENTOR 1000 with maximal reached force about 9 – 12 N (Figure. 1). The force F (N) and elongation Δl (mm) were measured when the speed of flat grip fixtures was 200 mm*min^{-1} and data were stored in xls format in the computer.

Figure 1. Test stand ANDILOG STENTOR 1000 with the foil sample

The force and elongation were transformed by means of software Microsoft Office Excel 2003 on the tensile stress σ (MPa) and the strain ε (mm*mm^{-1}). The tensile stresses σ (MPa) were determined from the equation (1)

$$\sigma = \frac{F}{S}, \qquad (1)$$

where F(N) is force and S(mm^2) is an initial cross section of the foils. The strains ε (mm*mm^{-1}) were determined as a change in the specimen's gage length from the equation (2)

$$\varepsilon = \frac{\Delta l}{L_0}, \qquad (2)$$

where Δl (mm) is the gain distance between grips and L_0 is initial length of the sample 150 mm. Tensile modulus of elasticity E (MPa) is defined as the stress change divided by change in strain within the linear region of the stress/strain curves (3)

$$E = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1}, \qquad (3)$$

where σ_1 is the stress equivalent the strain ε_1 = 0.0005 mm*mm^{-1} and σ_2 is the stress equivalent the strain ε_2 = 0.0025 mm*mm^{-1}. Modulus values were calculated by taking the slope of stress versus strain curves but in the range of strains from 0.0005 mm.mm^{-1} to 0.0025 mm*mm^{-1} (0.05 % – 0.25 %) where the stress/strain dependency is linear (STN EN ISO 527–1). There was problem to adhere the terms because the test stand fails to measure all data at the beginning of the measurement. The breaking strength determined by σ_b (MPa) and ε_b (mm*mm^{-1}) were also measured in the time of the rupture of the foils.

Results and disccussion

At low stresses most samples indicated a linear viscoelastic response. The example of tensile stress/strain diagram of the longitudinal polyethylene foil sample with colored concentrate Maxithen HP 533041 – violet are presented at the Fig. 2. The dependency presents the region of linear viscoelasticity, to the value of the strain 0.0025 mm*mm^{-1} than the region of the viscoelasticity to the value of the strain about 0.060 mm*mm^{-1} and the region of the plasticity over the strain 0.060 mm*mm^{-1}. The breaking strength was determined as the stress 10.16 MPa at the strain 1.59 mm*mm^{-1}. The resulting modulus of elasticity observed in Fig. 3 was 287.9 MPa.

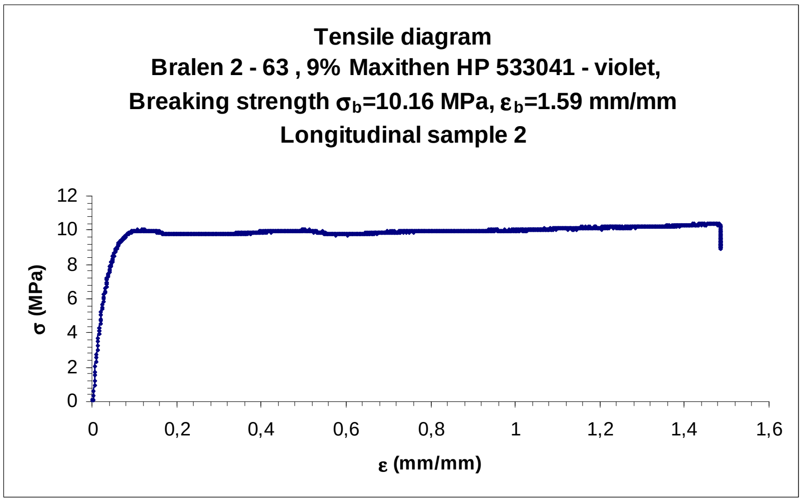

Figure 2. Tensile stress – σ/strain – ε diagram of polyethylene sample Bralen RA 2 – 63 with color concentrate Maxithen HP 533041 – violet for longitudinal sample 2 and values of breaking strength σ_b=10.16 MPa and ε_b=1.59 mm*mm^{-1}

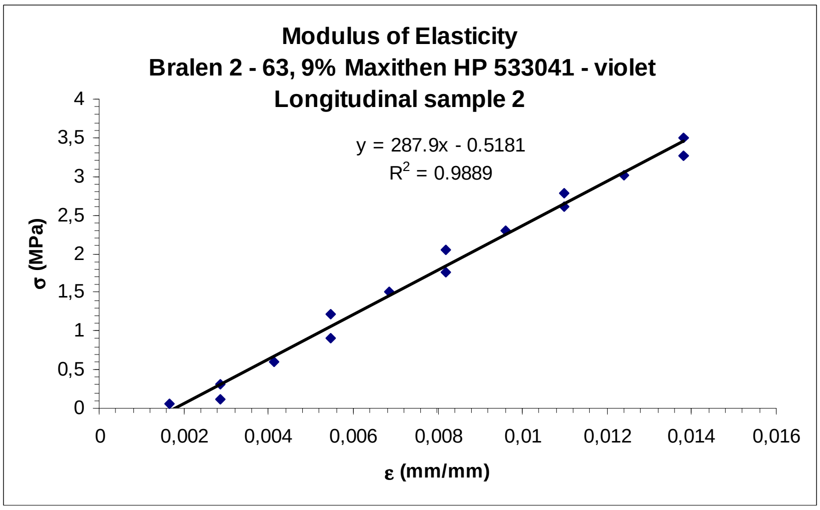

Figure 3. Determination of modulus of elasticity E=287.9 MPa in the linear strain region of polyethylene longitudinal sample 2 Bralen RA 2 – 63 with color concentrate Maxithen HP 23111 – violet

Modulus of elasticity was obtained from the slope of the regression line of the Fig. 3 and no from the Eq. (3), because the initial interval of the measured strains was measured only from 0.0016 mm*mm^{-1}. This problem was caused by the fixation of the samples in the flat grip fixtures and the initial data acquisition. The example of tensile stress/strain diagram of the transversal polyethylene foil sample with colored concentrate Maxithen HP 533041 – violet are presented at the Figure 4. The breaking strength is determined by the stress 12.82 MPa and the strain 1.50 mm*mm^{1}. The resulting modulus of elasticity observed in Fig. 5 was 166.68 MPa.

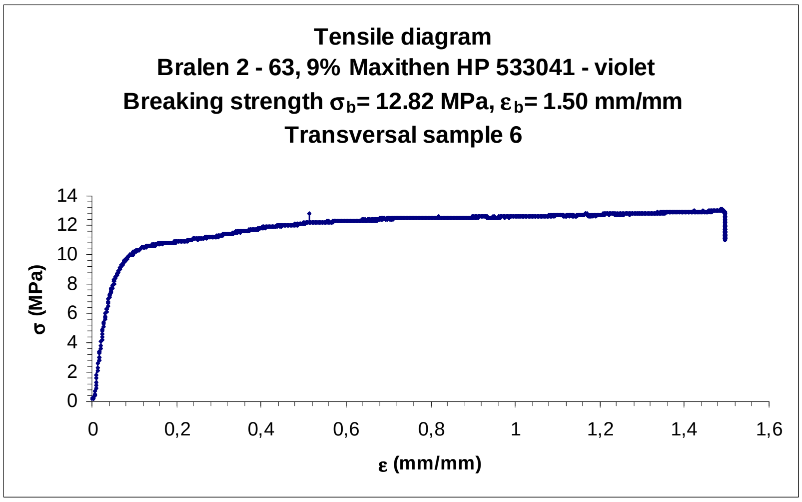

Figure 4. Tensile stress – σ/strain – ε diagram of polyethylene sample Bralen RA 2 – 63 with color concentrate Maxithen HP 533041 – violet for transversal sample 6 and values of breaking strength σ_b=12.82 MPa and ε_b=1.50 mm*mm^{-1}

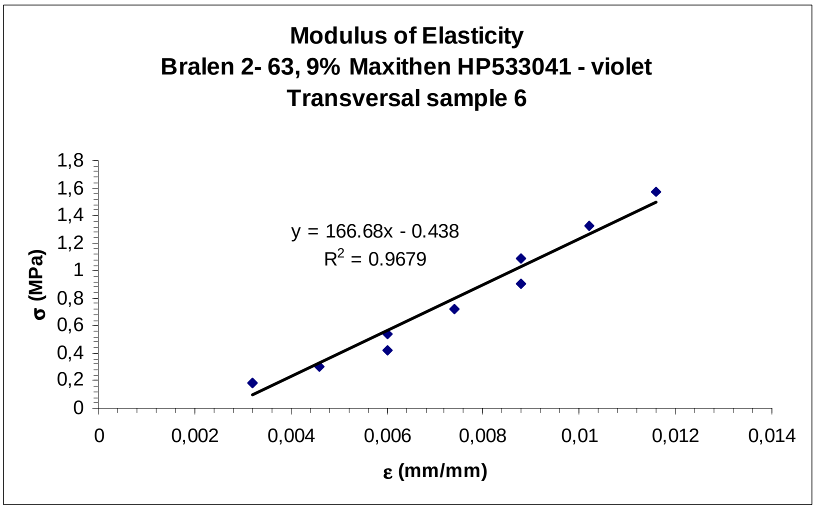

Figure 5. Determination of modulus of elasticity E=166.68 MPa in the linear strain region of polyethylene transversal sample 2 Bralen RA 2 – 63 with color concentrate Maxithen HP 23111 – violet

Modulus of elasticity was also obtained from the slope of the regression line of the Fig. 5 and no from the Eq. (3) as was realized for longitudinal sample, because the initial interval of the measured strains was measured only from 0.0028 mm*mm^{-1}. We supposed that the trend of the initial line, used for the determination of the modulus of elasticity was the same as in the range from 0.0005 mm*mm^{-1} to 0.0025 mm*mm^{-1}.

The results of the examined foils are presented in the Table 1 and the Table 2 for the longitudinal and transversal samples respectively.

Table 1. Results of the modulus of elasticity E (MPa), the stress and strain in the moment of the rupture σ_b (MPa) and ε_b (mm*mm^{-1}) respectively of the longitudinal samples and their standard deviations of the yellow, white, blue and violet foils Bralen RA 2 – 63

Sample	Longitudinal					
	Mean	Std	Mean	Std	Mean	Std
	E (MPa)	s_E (%)	σ_b (MPa)	s_b(%)	ε_b (mm*mm^{-1})	s_ε (%)
Yellow	250.92	5.40	12.55	0.95	1.54	1.64
White	222.73	8.04	13.33	0.91	1.51	0.49
Blue	228.87	10.83	9.46	0.98	1.51	0.75
Violet	298.24	2.29	10.26	0.58	1.49	1.43

Std – standard deviation

Table 2. Results of the modulus of elasticity E (MPa), the stress and strain in the moment of the rupture σ_b (MPa) and ε_b (mm*mm^{-1}) respectively of the transversal samples and their standard deviations of the yellow, white, blue and violet foils Bralen RA 2 – 63

Sample	Transversal					
	Mean	Std	Mean	Std	Mean	Std
	E (MPa)	s_E (%)	σ_b (MPa)	s_σ(%)	ε_b (mm*mm^{-1})	s_ε (%)
Yellow	270.41	7.50	12.40	0.89	1.58	0.60
White	179.61	13.31	15.54	0.70	1.51	0.24

Blue	207.89	9.67	13.00	0.64	1.51	0.67
Violet	220.33	10.13	12.38	2.32	1.48	0.84

Std – standard deviation

The mean values were determined from ten samples of the foils. The mean values of the moduli of elasticity E(MPa) of the longitudinal and transversal samples exhibited similar size respectively. There were not significant differences among the elastic values of the longitudinal and transversal properties of the foils. The biggest standard deviations were obtained of measurement of blue longitudinal samples (10.83 %) and white transversal samples (13.31 %). The stresses and strains in the moment of the rupture σ_b (MPa) and ε_b ($mm*mm^{-1}$) were also similar for longitudinal and transversal samples. The standard deviations of the strains and the stresses in the moment of rupture had lower order than the moduli of elasticity. They were measured more precisely. The smaller precision of the moduli of elasticity was probably induced by the problems with the measurement and record of the initial values of the force and the elongation by the test stand STENTOR ANDILOG 1000. Brandrup et al, (1999) introduce the moduli of the polyethylene material into the range of 55 to 172 MPa. The values of the moduli of elasticity of low density polyethylene (LDPE) are presented in the range from 111 MPa to 449 MPa (Matweb, 2013).

Conclusions

Tensile properties of the polyethylene foils are important for advisement of mechanical condition of the materials. Tensile properties of the foils were studied only in the linear viscoelastic region of foil deformations. In consequence viscoelastic behaviour of the polymers a lot of properties depend not only on the temperature, but also on the time. The stress–strain dependency of the tensile test is nonlinear even in the range of linear viscoelasticity. This effect is typical of the tenacious polymers. For that reason the values of the tangential modulus tenacious materials, determined from the initial part of the curve stress/strain, often depend on the applied scale factor. From that reason the method of the measurement of the modulus of elasticity was based on two specific values of the strain, i. e. 0.05 % and 0.25 %. Our measurement were realized in the near region of these values.

References

Brandrup, J., Immergut, E. H., Grulke, E. A., (1999) Polymer Handbook. 4nd Ed., Wiley, New York, 2000 p.

Foreman, J., Gill, P.S., Sauerbrunn, S.R., (2010) Tensile modulus of plastic films [online]. Published: May, 12th 1997. Available at: http://www.tainstruments.com/main.aspx?n=2&id=181&main_id=355&siteid=11. [Accessed 17 June 2013].

Ibarra-Jimenez, L., Quezada-Martin, R., Cedeno-Rubalcava, B., Rio, A. J. L., de la Rosa-Ibarra, M., (2006) Watermelon response to plastic mulch and row covers. European Journal of horticultural science, 2006, 71, (6), 262–266.

Romic, D. (2003) Polyethylene mulches and drip irrigation increase growth and yield in watermelon (*Citrullus lanatus* L.). European journal of horticultural science, 68, (4), 192–198.

Matweb (2013) Overview of materials for Low Density Polyethylene (LDPE), Molded [online]. Published: 1996 – 2013. Available at: http://www.matweb.com/search/datasheet.aspx?MatGUID=557b96c10e0843dbb1e830ceedeb35b0. [Accessed 17 June 2013].

Taber, H. G. (2010) Mulches and Drip Irrigation for High Tunnels. Iowa High TunnelFruit and Vegetable Production Manual [online]. Published: June, 18th 2010. Available at: http://www.extension.iastate.edu/Publications/PM2098.pdf. [Accessed 17 June 2013].

STN EN ISO 527–1 (1997) Plastics. Determination of tensile properties. Part 1. General principles.

STN EN ISO 527–2 (1997) Plastics. Determination of tensile properties. Part 2. Test conditions for moulding and extrusion plastics.

STN EN ISO 527–3 (1997) Plastics. Determination of tensile properties. Part 3. Test conditions for films and sheets.