MARIAN ŻENKIEWICZ

Institute for Plastics Processing "Metalchem"
ul. M. Skłodowskiej-Curie 55, 87-100 Toruń, Poland

Investigation of tensile properties and tear resistance of polypropylene film modified by irradiation

RAPID COMMUNICATION

Summary — Results of investigation of rupture strength, ultimate elongation, and tear resistance of a flat polypropylene film oriented biaxially and modified with use of the electron radiation are presented. It was found that the rupture strength and ultimate elongation of the sample under study dropped to values several times lower when the radiation dose increased from 25 to 500 kGy. At the same time, tear resistance of the sample decreased very quickly, what disqualifies the film as a wrapping material.

Key words: polypropylene film, radiation modification, tensile properties.

Treating of medical equipment and materials made of polypropylene with a high-energy electron beam is one of the methods used for sterilization. However, this treatment leads also to variations in both molecular and supermolecular structure, as well as to altering of physical and mechanical properties of polypropylene. The polymer degrades intensively with increasing radiation doses. In result, strength of the polypropylene film decreases, making the material useless.

Initial stage of irradiation results in evolution of alkyl and allyl radicals [1, 2]. These radicals are the main stimulators of further processes, such as cross-linking, degradation, and oxidation. The latter proceeds most rapidly in the outermost layer of the polypropylene film due to direct access of atmospheric oxygen. Under ambient temperature, radicals at the tertiary carbon atoms are most durable. They are mobile, may migrate to the interface, and can transform into peroxide radicals when reacting with oxygen.

Degradation of polypropylene upon the electron radiation may proceed according to the following mechanisms [3, 4]:

$$\begin{aligned} &-CH_2-CH(CH_3)-CH_2-CH(CH_3)-CH_2- \longrightarrow \\ &\longrightarrow -CH_2-C^{+}H(CH_3) + \dot{C}H_2-CH(CH_3)-CH_2- + e^- \end{aligned} \tag{1}$$

$$\begin{aligned} &-CH_2-CH(CH_3)-CH_2-CH(CH_3)-CH_2- \longrightarrow \\ &\longrightarrow -CH_2-CH(CH_3)-C^{+}H_2 + \dot{C}H(CH_3)-CH_2- + e^- \end{aligned} \tag{2}$$

$$\begin{aligned} &-CH_2-CH(CH_3)-CH_2-CH(CH_3)- \longrightarrow \\ &\longrightarrow -CH(CH_3)-\dot{C}H_2 + \dot{C}H(CH_3)-CH_2- \longrightarrow \\ &\longrightarrow -C(CH_3)=CH_2 + CH_2(CH_3)-CH_2- \end{aligned} \tag{3}$$

$$\begin{aligned} &-CH_2-CH(CH_3)-CH_2-CH(CH_3)- \longrightarrow \\ &\longrightarrow H_2 + -C(CH_3)=CH_2 + CH(CH_2)-CH_2- \end{aligned} \tag{4}$$

Molecular weight of polypropylene decreases and polydispersity of the molecular weight change during the degradation process. Earlier studies [5, 6] on isotactic polypropylene showed that tensile strength dropped when the radiation dose increased.

The aim of this study was to investigate the changes in rupture strength, ultimate elongation and tear resistance of a biaxially oriented polypropylene film modified by electron radiation in air.

EXPERIMENTAL

Materials

A flat biaxially oriented polypropylene (BOPP) film of the Bifol AG 4001 type, 40 μm thick, obtained from PKN ORLEN SA (Płock, Poland) was examined. It had been produced from the Malen-PF 401 polypropylene, which contained a high fraction (*ca.* 97%) of the crystalline phase and was synthesized by means of a continuous polymerization with use of catalysts, including titanium salts supported on aluminum chloride. Mass flow index of this polymer was 2.6±0.2 g/10 min at the 2.16 kg load and 230°C.

Film modification

The BOPP film was modified by irradiation with a high-energy electron beam generated by an LAE 13/9 linear accelerator located at the Institute of Nuclear Chemistry and Technology in Warsaw, Poland. Maximum energy of accelerated electrons was 13 MeV, adjustable within the range of 5—13 MeV. Factual operating energy differed by not more than 6% from the set value. Average energy of accelerated electrons and average power of the electron beam were 10 MeV and 9 kW, respectively.

The irradiation procedure was as follows. A rectangular sample (50×42 cm) of the studied BOPP film with an attached dosimetric indicator was placed in an aluminum container placed on a conveyor moving with a defined velocity. The sample traveled through the irradiation zone just under the titanium window of the accelerator output. Conveyor velocity was 0.33 m/min and the radiation doses applied were from 25 to 500 kGy.

Test methods

Rupture strength and ultimate elongation of the film were examined with use of a TIRAtest 2705 testing machine (TIRA Maschinenbau GmbH, Germany). The investigations were performed according to standards [7, 8]. Samples in the form of 100 mm long and 15 mm wide strips were cut out from a sheet along two axes: parallel and perpendicular to the extrusion direction. Next, the samples were secured in the drawing jaws of the tester so that the operating length of a sample was 50 mm. The tester's moving jaw velocity was 100 mm/min. In order to determinate the tensile stress (δ), equal to rupture strength, was determined by examining five samples of the film irradiated with a given dose and calculating the average δ value. Ultimate elongation (ε) was determined analogously.

Tear resistance (*R*) was measured by applying the standard Elmendorf method [9], using an Elmendorf Pro Tearing Tester Model 60-2200 (Twing Albert Instrument Co., USA) equipped with a microprocessor controller that enabled high accuracy and repeatability of the measurements. During an experiment, force necessary to tear a film sample with use of a 1.6 kg pendulum was measured. Similarly as given above, five samples of the film irradiated with a given dose were examined and an average value of *R* was calculated.

RESULTS AND DISCUSSION

Complex studies of the influence of electron radiation on different properties of a polypropylene film (not reported in the present work), including investigations performed using photoelectron spectroscopy and electron paramagnetic resonance, confirm path of the irradiation processes occurring in polypropylene, as presented in this paper.

Measurements of rupture strength, ultimate elongation, and tear resistance of a polypropylene film modified by electron irradiation were performed in relation to two axes: parallel (1) and perpendicular (2) to the extrusion direction. Results are shown in Figs. 1—3.

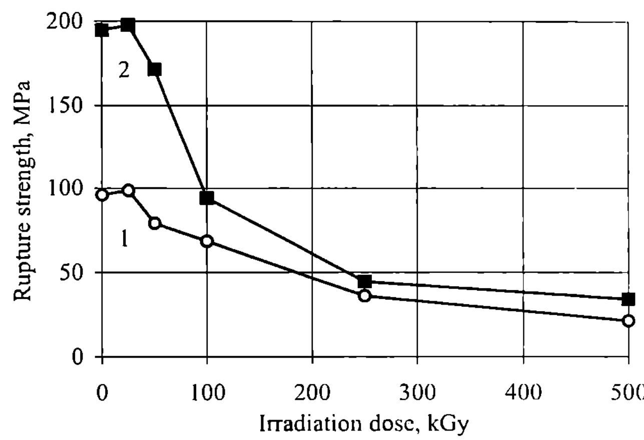

Fig. 1. Influence of dose on rupture strength of the BOPP film (lines 1, 2 — see text)

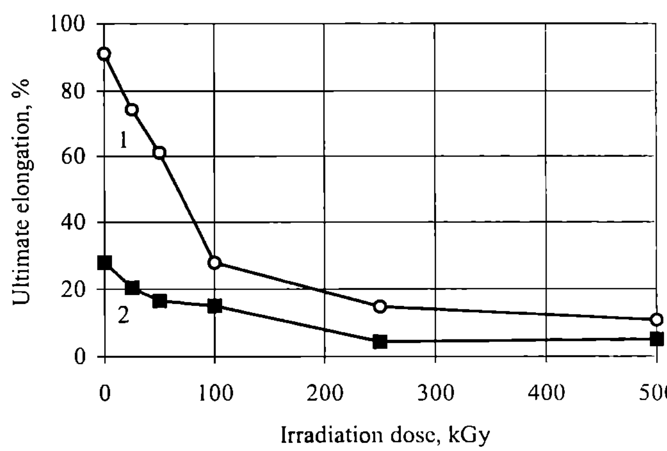

Fig. 2. Influence of dose on ultimate elongation of the BOPP film

It was found that the rupture strength of the BOPP film initially increased slightly with growing electron irradiation dose (in the range of up to 25 kGy) and thereafter decreased dramatically due to progressive degradation of polypropylene. May be this initial increase is caused by crosslinking process going under influence of small doses of radiation. Especially rapid decrease of rupture strength (*ca.* 0.75 MPa/kGy) was observed in the 25—100 kGy range for samples tested in the perpendicular axis. In the range of up to 100 kGy, rupture strength

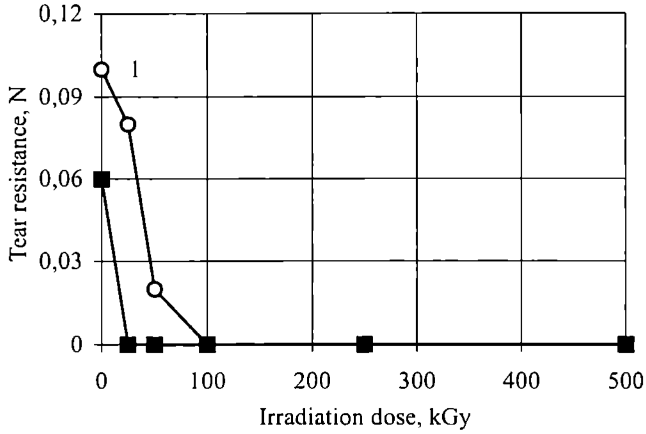

Fig. 3. Influence of dose on tear resistance of the BOPP film

along the perpendicular axis was much higher than that along the parallel axis. Difference between the rupture strength values was due to the difference in the stretch of the BOPP film during its production process. Decrease in rupture strength above 100 kGy was relatively slow (0.1—0.15 MPa/kGy) and the strength values for both axes were similar.

Ultimate elongation varied with the electron irradiation dose similarly to that reported for rupture strength. However, tear resistance decreased rapidly already at low radiation doses. It reached zero at doses below 25 and 100 kGy for the perpendicular and parallel axes, respectively.

CONCLUSIONS

This study has provided further evidence that:

— Rupture strength of the BOPP film initially increased slightly with the electron irradiation dose increasing up to 25 kGy and subsequently decreased to values several times lower.

— Tear resistance decreased rapidly already at low radiation doses, what disqualifies the BOPP film as a wrapping material.

— Thorough investigations using the electron irradiation doses under 25 kGy should be performed in order to determine the dose at which the tear resistance would be sufficiently high for the film to be applied as the wrapping material.

ACKNOWLEDGMENT

The work was supported by the State Committee for Scientific Research (KBN) with the grant No 7 T08E 052 20.

REFERENCES

1. Charlesby A.: "Atomic Radiation and Polymers", Pergamon Press, London 1960.
2. Dole M.: "The Radiation Chemistry of Macromolecules", Academic Press, New York 1972.
3. Żenkiewicz M., Czupryńska J.: *Plasty a Kaučuk* 2001, **38**, 263.
4. Czupryńska J.: *Polimery* 2002, **47**, 8.
5. Gorelik B. A., Grigoriev A. G., Semenenko E. I., Sokolova L. A.: *Radiat. Phys. Chem.* 1990, **35**, 213.
6. Khoylou F., Katbab A. A.: *Radiat. Phys. Chem.* 1993, **42**, 219.
7. PN-EN ISO 527-1:1998.
8. PN-EN ISO 527-3:1998.
9. PN-ISO 6383-2:2000.

Received 5 VIII 2002.