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LOCAL MECHANICAL PROPERTIES OF IRRADIATED CROSS-LINKED HDPE

LOKALNE MEHANSKE LASTNOSTI PREČNO VEZANEGA HDPE PO MOČNEM RADIOAKTIVNEM OBSEVANJU β

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Using high doses of beta radiation for high-density polyethylene (HDPE) and its influence on the changes in the micromechanical properties of the surface layer has not been studied in detail so far. Specimens of HDPE were made with the injection-moulding technology and irradiated with high doses of beta radiation (0, 132, 165 and 198) kGy. The changes in the micromechanical properties of the surface layer were evaluated using an ultra nano-hardness test. The results of the measurements showed a considerable increase in the micromechanical properties (indentation hardness, indentation elastic modulus) when high doses of beta radiation are used. The aim of this paper is to study the effect of ionizing radiation at different doses on the ultra nano-hardness of the surface layer of HDPE and compare these results with those for non-irradiated samples. The study was carried out due to the ever-growing use of this type of polymer HDPE.

Keywords: high-density polyethylene (HDPE), surface layer, mechanical properties, ultra nano–hardness

Avtorji prispevka so raziskovali vpliv močnega radioaktivnega sevanja β na mikromehanske lastnosti površinskih plasti polietilena z veliko gostoto (HDPE), kar do sedaj ni natančneje raziskoval še nihče. Vzorce HDPE so izdelali s tehnologijo injekcijskega brizganja in jih obsevali z visokimi dozami (0, 132, 165 in 198) kGy radioaktivnega sevanja β. Mikromehanske lastnosti površinskih plasti obsevanih vzorcev so določili z merjenjem ultra nanotrdote. Rezultati meritev so pokazali znatno povišanje mikromehanskih lastnosti (nanotrdote in elastičnega modula vtiskovanja) močno obsevanih vzorcev. Namen tega prispevka je prikazati vpliv radioaktivnega sevanja β različnih jakosti na površinske plasti HDPE in primerjavo z neobsevanim vzorcem. Raziskava je bila izdelana zaradi vse večje uporabe tega polimernega materiala v pogojih radioaktivnega sevanja.

Ključne besede: polietilen z veliko gostoto (HDPE), površinska plast, mehanske lastnosti, ultra nanotrdota

1 INTRODUCTION

The irradiation cross-linking of thermoplastic materials via an electron beam or cobalt 60 (gamma rays) proceeds separately after the processing. The cross-linking level can be adjusted with the irradiation dosage and often by means of a cross-linking booster.

The main deference between β- and γ-rays (**Figure 1**) is in their different abilities of penetrating the irradiated material; γ-rays have a high penetration capacity. The penetration capacity of electron rays depends on the energy of the accelerated electrons.

Thermoplastics used for the production of various types of products have very different properties. Standard polymers that are easily obtained at favourable price conditions belong to the main class. The disadvantage of standard polymers relates to both the mechanical and thermal properties. The group of standard polymers is the most considerable one and its share in the production of all polymers is as high as 90 %.

Engineering polymers are a very important group of polymers, exhibiting much better properties in comparison to those of standard polymers. Both mechanical and thermal properties are much better than in the case of standard polymers. The production of these types of polymers accounts for less than 1 % of all the polymers.[1–6]

High-performance polymers have the best mechanical and thermal properties but their share in the production and use of all the polymers is less than 1 %.

The present work deals with the influence of beta irradiation on the mechanical properties of the surface layer of injection-moulded HDPE.

2 EXPERIMENTAL PART

For this experiment, high-density polyethylene (HDPE) DOW – HDPE 25055E, the DOW Chemical Company, USA (unfilled, HDPE) – was used. Irradiation was carried out at the company BGS Beta-Gamma-Service GmbH & Co, KG, Germany, using electron rays, an electron energy of 10 MeV, and doses of (0, 132, 165 and 198) kGy in air at ambient temperature.

Samples (**Figure 2**) were made using the injection-moulding technology on an injection-moulding machine Arburg Allrounder 420C. The processing temperature was 245–295 °C, the mould temperature was 85 °C, the injection pressure was 80 MPa and the injection rate was 45 mm/s.[7–11]

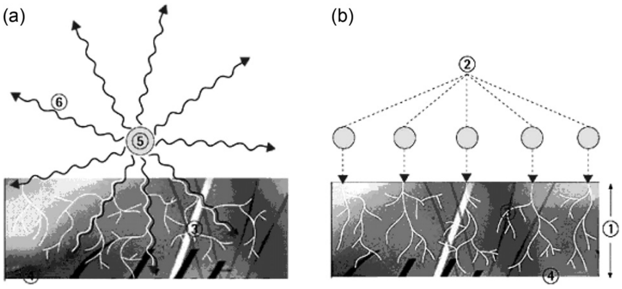

Figure 1: a) design of gamma rays and b) electron rays: 3 – secondary electrons, 4 – irradiated material, 5 – encapsulated Co-60 radiation source, 6 – gamma rays, b) 1 – penetration depth of electrons, 2 – primary electrons, 3 – secondary electrons, 4 – irradiated material

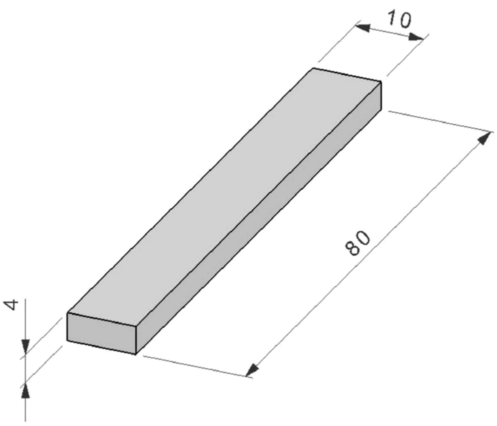

Figure 2: Dimensions of a sample

A nanoindentation test was done using an ultra nanoindentation tester (UNHT), CSM Instruments (Switzerland), according to the CSN EN ISO 14577. The load and unload speed was 1000 N/min. After a holding time of 90 s at the maximum load of 500 μN, the specimens were unloaded. The specimens were glued onto metallic sample holders (**Figure 2**).[7–11]

$$H_{IT} = F_{max}/A_p \qquad (1)$$

Here H_{IT} is the indentation hardness, F_{max} is the maximum applied force, and A_p is the projected area of contact between the indenter and the test piece determined from the force-displacement curve and the knowledge of the area function of the indenter.[7–11]

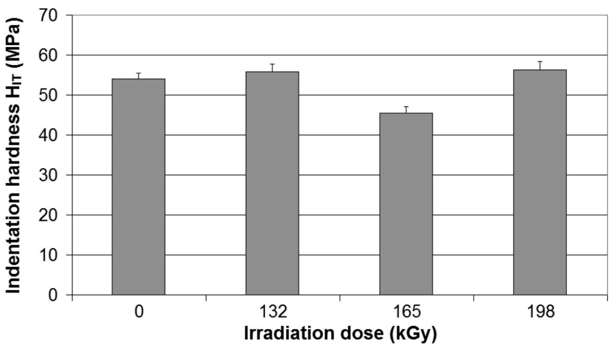

Figure 3: Indentation hardness H_{IT}

3 RESULTS

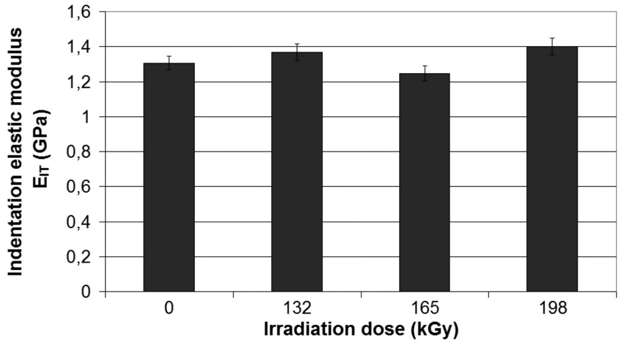

Figure 4: Indentation elastic modulus E_{IT}

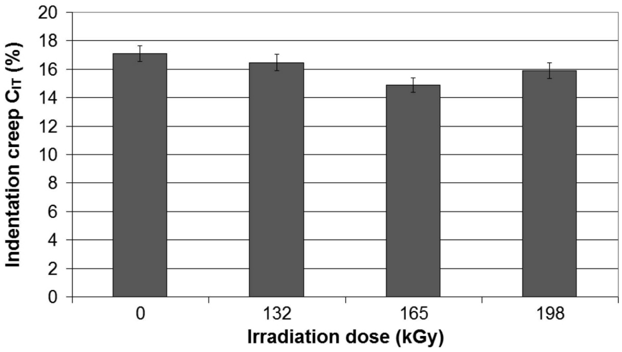

Figure 5: Indentation creep C_{IT}

4 DISCUSSION

The development of the micromechanical properties of the irradiated high-density polyethylene (HDPE) was characterized with a test of the ultra nano-hardness (H_{IT}), as can be seen in **Figure 3**. The lowest value (45 MPa) of the indentation hardness was found for the high-density polyethylene (HDPE) irradiated with the dose of 165 kGy, while the highest value of the indentation hardness was found for the non-irradiated high-density polyethylene (56 MPa). The increase in the indentation hardness at the 198 kGy radiation dose was 4 % compared to the non-irradiated high-density polyethylene (HDPE).

A similar development was recorded for the micro-stiffness of the specimens represented by the indentation elastic modulus (E_{IT}) illustrated in **Figure 4**. The results of the measurements show clearly that the lowest value of the indentation elastic modulus was measured for the high-density polyethylene (HDPE) (1.24 GPa) irradiated with the dose of 165 kGy, while the highest value was found for the high-density polyethylene (HDPE) irradiated with 198 kGy (1.4 GPa). A significant increase in the indentation elastic modulus (7 %) was recorded at the radiation dose of 198 kGy, compared to the non-irradiated high-density polyethylene (HDPE).

Very important values were found for the indentation creep. For the materials, which creep as polymers, the basic calculation of the creep can be measured during a pause at the maximum force. The creep is a relative change of the indentation depth when the test force is kept constant. The results of the test of the ultra nano-hardness, **Figure 5**, show that the highest creep value was measured at the 0 kGy radiation dose (17 %), while the lowest creep value was found for the high-density polyethylene (HDPE) irradiated with the 165 kGy dose (14 %). The creep decreased by 13 % because of the radiation, which is a considerable increase in the surface-layer resistance.

5 CONCLUSIONS

This article deals with the measurements of the mechanical properties of a high-density polyethylene (HDPE) surface layer modified with beta radiation. Injection-moulded test bodies were irradiated with beta radiation using doses of (0, 132, 165 and 198) kGy. The measurements of the mechanical properties were realized with an ultra nano-hardness tester.

The measurement results show an improvement in the chosen mechanical properties. The micro-hardness of the high-density polyethylene (HDPE) surface layer irradiated with the 198 kGy dose increased by 4 %. The rigidity of the tested surface layer represented by the modulus of elasticity increased by 7 % for the sample irradiated with the 198 kGy dose. The creep of the tested surface layer decreased from 17 % for the non-irradiated sample to a value of 14 % for the sample irradiated with the 165 kGy dose.

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