Effect of Beta Irradiation on the Microhardness of HDPE

MARTIN OVSÍK, DAVID MANAS, MIROSLAV MANAS, MICHAL STANEK, KAMIL KYAS,
MARTIN BEDNARIK, ALES MIZERA
Tomas Bata University in Zlin
TGM 5555, 760 01 Zlin
Czech Republic
ovsik@ft.utb.cz    http://www.ft.utb.cz

Abstract: - Hard surface layers of polymer materials, especially HDPE, can be formed by chemical or physical process. One of the physical methods modifying the surface layer is radiation cross-linking. Radiation doses used were 0, 33, 99, 132, 165 and 199 kGy for HDPE. Individual radiation doses caused structural and micromechanical changes which have a significant effect on the final properties of the HDPE tested. Radiation doses cause changes in the surface layer which make the values of some material parameters rise. The improvement of micromechanical properties was measured by an instrumented microhardness test.

Key-Words: - HDPE, microhardness, irradiation, crosslinking, β – radiation, surface layer

1 Introduction

A linear polymer, High Density Polyethylene (HDPE) is prepared from ethylene by a catalytic process. The absence of branching results in a more closely packed structure with a higher density and somewhat higher chemical resistance than LDPE. HDPE is also somewhat harder and more opaque and it can withstand rather higher temperatures (120° Celsius for short periods, 110° Celsius continuously) [1] [4].

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

The main deference between β- and γ- rays 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.

Due to electron accelerators the required dose can be applied within seconds, whereas several hours are required in the γ-radiation plant.

The electron accelerator operates on the principle of the Braun tube, whereby a hot cathode is heated in vacuum to such a degree that electrons are released [2] [3] [15] [16].

Simultaneously, high voltage is generated in a pressure vessel filled with insulating gas. The released electrons are accelerated in this vessel and made to fan out by means of a magnetic field, giving rise to a radiation field. The accelerated electrons emerge via a window (Titanium foil which occludes the vacuum) and are projected onto the product [3] [7] [10].

Cobalt 60 serves as the source of radiation in the gamma radiation plant. Many of these radiation sources are arranged in a frame in such a way that the radiation field is as uniform as possible. The palleted products are conveyed through the radiation field. The radiation dose is applied gradually, that is to say, in several stages, whereby the palleted products are conveyed around the Co – 60 radiation sources several times. This process also allows the application of different radiation doses from one product type to another. The dimensional stability, strength, chemical resistance and wear of polymers can be improved by irradiation. Irradiation cross-linking normally creates higher strength as well as reduced creep under load if the application temperature is above the glass transition temperature (Tg) and below the former melting point. Irradiation cross-linking leads to a huge improvement in resistance to most of the chemicals and it often leads to the improvement of the wear behaviour [3] [4].

The thermoplastics which are used for production of various types of products have very different properties. Standard polymers which are easy obtainable with favourable price conditions belong to the main class. The disadvantage of standard polymers is limited both by 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%.
The engineering polymers are a very important group of polymers which offer much better properties in comparison to those of standard polymers. Both mechanical and thermal properties are much better than in case of standard polymers. The production of these types of polymers takes less than 1 % of all polymers [1] [6].

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

The present experimental work deals with the influence of beta irradiation on the microhardness of HDPE.

2 Experimental
For this experiment High Density Polyethylene HDPE DOW – HDPE 2505E, DOW - Chemical company, USA (unfilled, HDPE ) was used. The prepared specimens were irradiated with doses of 0, 33, 99, 132, 165 and 199 kGy at BGS Beta-Gamma Service GmbH & Co. KG, Germany.

The samples were made using the injection molding technology on the injection moulding machine Arburg Allrounder 420C. Processing temperature 200–240 °C, mold temperature 40 °C, injection pressure 80 MPa, injection rate 60 mm/s.

Instrumented microhardness tests were done using a Micro Combi Tester, CSM Instruments (Switzerland) according to the CSN EN ISO 6507-1. Load and unload speed was 2 N/min. After a holding time of 90 s at maximum load 1 N the specimens were unloaded. The indentation hardness H IT was calculated as maximum load to the projected area of the hardness impression according to:

\[ H_{IT} = \frac{F_{\text{max}}}{A_p} \quad \text{with} \quad h_c = h_{\text{max}} - \varepsilon \frac{F_{\text{max}}}{S} \quad (1) \]

where \( h_{\text{max}} \) is the indentation depth at \( F_{\text{max}} \), \( h_c \) is contact depth. In this study the Oliver and Pharr method was used calculate the initial stiffness (S), contact depth (\( h_c \)). The specimens were glued on metallic sample holders [5] [6].

The indentation modulus is calculated from the Plane Strain modulus using an estimated sample Poisson’s ratio:

\[ E_{p} = E^* (1 - \nu^2) \quad (2) \]

The deduced modulus is calculated from the following equation:

\[ E_r = \frac{\sqrt{\pi} \cdot S}{2 \cdot \beta \cdot \sqrt{A_p (h_c)}} \quad (3) \]

The Plane Strain Modulus \( E^* \) is calculated from the following equation:

\[ E^* = \frac{1}{1 - \nu_i^2} \frac{1}{E_r} \frac{1}{E_i} \quad (4) \]

Where \( E_i \) is the Elastic modulus of the indenter, \( E_r \) is the Reduced modulus of the indentation contact, \( \nu_i \) is the Poisson’s ratio of the indenter.

Determination of indentation hardness \( C_{IT} \):

\[ C_{IT} = \frac{h_2 - h_1}{h_1} \cdot 100 \quad (5) \]

Where \( h_1 \) is the indentation depth at time \( t_1 \) of reaching the test force (which is kept constant), \( h_2 \) is the indentation depth at time \( t_2 \) of holding the constant test force [1] [4] [5].
3 Results and discussion

The values measured during the microhardness test showed that the lowest values of indentation hardness were found for the non-irradiated HDPE. On the contrary, the highest values of indentation hardness were obtained for HDPE irradiated by a dose of 132 kGy (by 30% higher in comparison with the non-irradiated HDPE), as can be seen at Fig. 3.

Higher radiation dose does not influence significantly the microhardness value. An indentation hardness increase of the surface layer is caused by irradiation cross-linking of the tested specimen. A closer look at the microhardness results reveals that when the highest radiation doses are used, microhardness decreases which can be caused by radiation induced degradation of the material.

According to the results of measurements of microhardness, it was found that the highest values of indentation modulus of elasticity were achieved at the HDPE irradiated with dose of 132 kGy (by 26% higher than compared with non-irradiated HDPE). On the contrary, the lowest values of the indentation modulus of elasticity were found for non-irradiated HDPE as is seen at Fig. 4.

The lowest values of hardness Vickers were found for the non-irradiated HDPE. On the contrary, the highest values of hardness Vickers were obtained for HDPE irradiated by a dose of 132 kGy (by 29% higher in comparison with the non-irradiated HDPE), as can be seen at Fig. 5.

According to the results of measurements of microhardness, it was found that the lowest values of indentation creep were achieved at the HDPE irradiated with dose of 165 kGy (by 12% lower than compared with non-irradiated HDPE). On the contrary, the highest values of the indentation creep were found for non-irradiated HDPE as is seen at Fig. 6.

4 Conclusion

The article is the assessment of mechanical properties (microhardness) of the surface layer of modified HDPE. The surface layer of the polymer material such as HDPE is modified by β – radiation with doses of 33, 99, 132, 165 and 199 kGy.
Very interesting results were obtained for irradiation modified HDPE. When comparing the irradiated and non-irradiated HDPE it was apparent that the values of indentation hardness, elastic modulus considerably increased, in some cases even by 30% at the irradiation dose of 132kGy. Also different depths of indentation in the surface layer of tested specimen were significantly different. It also proved the fact that higher doses of radiation do not have very positive effects on the mechanical properties, on the contrary due to degradation processes the properties deteriorate.

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References: