CROSS-LINKED LOW DENSITY POLYETHYLENE MECHANICAL PROPERTIES AFTER TEMPERATURE LOAD AT 110, 180 AND 220 °C

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Radiation processing of polymers is a well-established and economical commercial method of precisely modifying the properties of polymers, especially mechanical properties. The mechanical properties of modified low density polyethylene samples by beta rays were measured at the ambient temperature and after temperature load above the pure low density polyethylene melting temperature. The tested samples showed significant changes of mechanical behaviour before and after temperature load. From this point of view, new applications could also be seen in areas with service temperatures higher than their former melting point, especially for application with short time exposure of temperature load.

KEYWORDS

mechanical properties, tensile test, radiation cross-linking, beta rays, low density polyethylene and temperature stability

1 INTRODUCTION

Polymers rank among a construction materials which find use in industry branches. The advantage of polymers is a low weight together with the excellent mechanical properties, very good chemical resistance and other properties, which assign them for various applications. Disadvantage is mainly low temperature stability which significantly reduces usage of these polymers.

Every property improvement especially temperature stability helps to increase application possibilities. In addition, property modifications of standard polymers, which are relatively cheap products, give them advantage for another usage.

The cross-linking of rubbers and thermoplastic polymers is a well-proven process of the improvement of the thermal properties. The chemical cross-linking or rubber vulcanization is normally induced by the effect of heating after processing with the presence of a curing agent. The cross-linking process for thermosets is very similar. In thermosets the polymer molecules are also chemically linked due to heat after processing. Cross-linked rubbers have a wide-meshed molecular network that keeps them soft and their properties change only slightly on a wide temperature scale. On the other hand, thermosets are characterized by a very narrow-meshed network. Due to this fact they hardly change their high level of stiffness on a wide temperature scale [Drobny 2010].

Radiation cross-linking with accelerating electrons offers several advantages when compared to other radiation sources, particularly gamma rays and X-rays [Clegg 1991]. The process is very fast, clean and can be controlled with a great deal of precision. In contrast to gamma rays and X-rays the electron beam can be steered relatively easy, thus allowing irradiation of variety of physical shapes [Tamboli 2004]. The large advantage includes flexibility and controllability in operation, beneficial economics, high throughput capability and the ability to switch off the source of radiation [Makuuchi 2012].

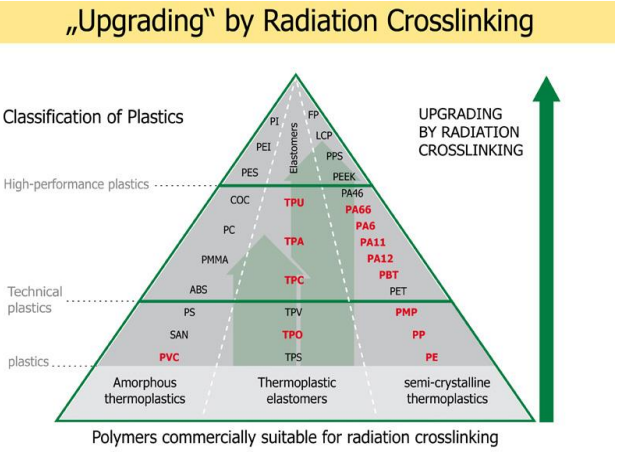

Figure 1. Pyramid of polymers [Makuuchi 2012]

As a result, we can optimise properties of commodity and engineering polymers and impart them the properties of high performance polymers [Khonakdar 2006]. Irradiation of polymers turned out to be interesting because of economic reasons, production costs and a life time of products [Clough 1996]. However, these benefits depend on the type of irradiated polymer and the radiation dosage. Behaviour of each material is different after irradiation [Hlangothi 2003]. We can not expect the improvement in all areas (mechanical, thermal and chemical) [Krupa 2001]. Most of polymers are not suitable for irradiation because of degradation and deterioration of their properties [Dadbin 2002].

This research paper deals with a possibility of using radiation cross-linked low density polyethylene as a suitable material for wire insulation in automotive industry, especially from point of view mechanical testing and temperature stability.

2 EXPERIMENTAL

As the basic polymer material was used low density polyethylene (DOW LDPE 780E). An ARBURG Allrounder 420C Advance Injection molding machine was used for sample preparation, with the processing conditional to comply with the low density polyethylene producer's recommendations.

Irradiation of tested low density polyethylene was performed with the kind help of BGS Germany, in the BGS Wiehl plant using accelerated electrons with a dosage range of 0 to 198 kGy. Then modificated samples with the dosage higher than 99 kGy were exposed temperature 110, 180 and 220 °C during 900 s and after that these samples were cooled spontaneously to ambient temperature.

Mechanical properties before and after temperature load and temperature stability of irradiated low density polyethylene after irradiation has been tested. The thermo-mechanical properties were measured. Perkin – Elmer Thermal Analyser TMA7 was used for the thermo-mechanical analysis, heated from 50 °C to 250 °C at 20 °C/min, hold for 1 min at 50 °C. The tensile behaviour of temperature non-loaded and loaded samples of LDPE were measured at the ambient temperature. Tensile test was carried out on tensile test machine ZWICK 1456 for LDPE according to standard CSN EN ISO 527-1, 527-2 with used rate 50 mm/min. Test data was processed by Test Expert Standard software and E-modulus [MPa], tensile strength [MPa] and elongation at break [%] were determined.

3 RESULTS AND DISCUSSION

As The tensile and temperature behaviour of low density polyethylene, before and after irradiation, was studied. For easier of evaluation of the measured data, and the comparison of the irradiated polymer with a non-irradiated one, the changes of measured were used on some graphs. The property of the non-irradiated polymer had the value of 100 %, while others were expressed in % as the ratio of measured property of irradiated polymers to the same property of non-irradiated polymer.

3.1 Temperature stability

The thermo-mechanical properties of LDPE were measured. The thermo-mechanical properties were evaluated by TMA measurement. The graphical depiction of TMA results are described the dose of radiation from 0 to 198kGy. Irradiation affects the thermo-mechanical properties of the studied LDPE (Fig. 2). Non-irradiated sample is melted at the temperature 110°C. Irradiated LDPE samples with the dose of irradiation 33 and 66kGy are soften at the temperature 140°C. LDPE with the increased dose above 99kGy is not lost the temperature stability up to 160°C. Irradiated LDPE specimens above the dose of irradiation 165 kGy evince the significant improvement of temperature stability.

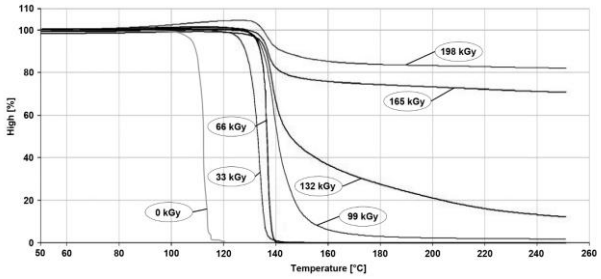

Figure 2. LDPE thermo-mechanical analysis

In the Fig. 3 and Fig. 4 it is possible to see comparison of LDPE samples before and after temperature load which was exposed 900 s at 220 °C. Non-modificated LDPE specimen was melted after temperature exposicion, however, the most irradiated (165 and 198 kGy) LDPE specimens was almost without shape changes. Irradiated LDPE specimens with the dosage of irradiation 99 and 132 kGy change them shapes visibly, especially in the lenght, there is about 10 % shortened.

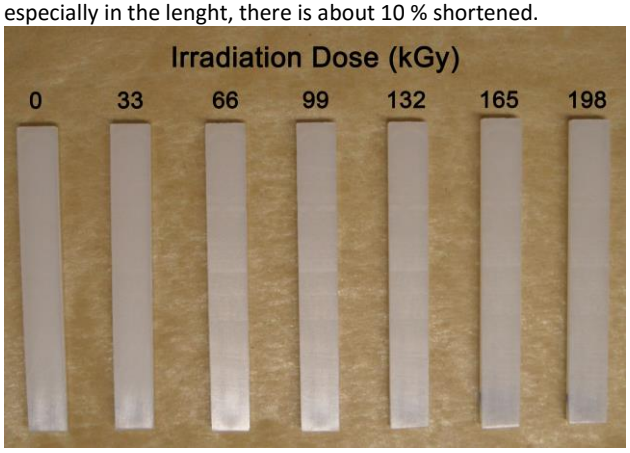

Figure 3. LDPE sample photography before temperature load

3.2 Tensile test

The Irradiation affects the tensile behaviour of the LDPE was studied at ambient temperature before and after temperature load. After performing the tensile test at ambient temperature three observed parameters (E-modulus, tensile strength, and elongation at break) were compared. The value of non-irradiated sample E-modulus was measured 305 MPa at 23°C.

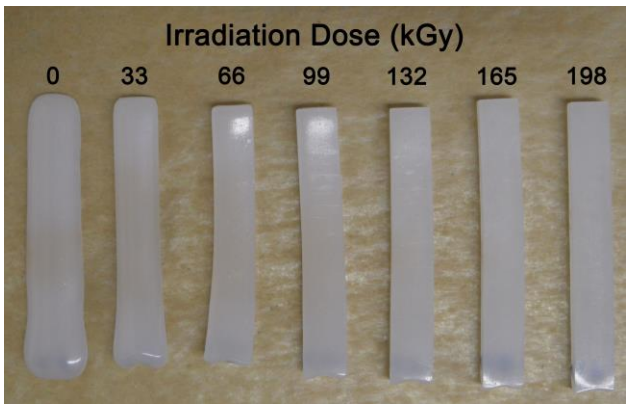

Figure 4. LDPE sample photography after temperature load during 900 s at 220 °C

As can be seen in Fig. 5, there was a significant growth of the E-modulus with dose of irradiation 66 kGy about 11 %. However, E-modulus with the increasing dose after temperature load decreases about 19 % in comparison of non-irradiated sample before temperature load.

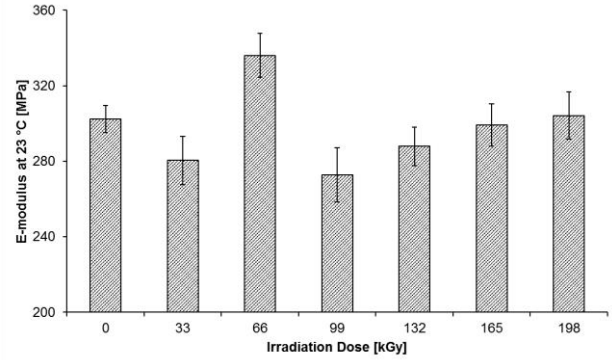

Figure 5. LDPE E-modulus at 23 °C

In the Fig. 6, Fig. 7 and Fig. 8 there are shown values of LDPE E-modulus after temperature load at 110, 180 and 220 °C with time exposition 900 s, respectively.

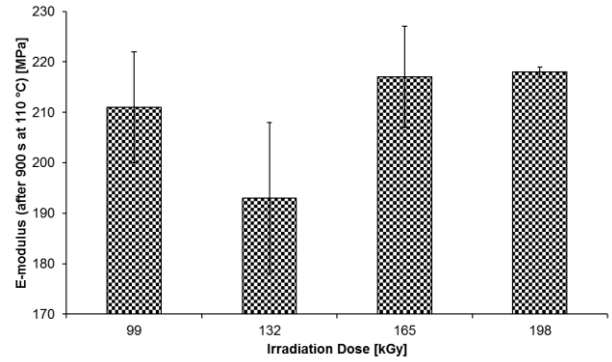

Figure 6. LDPE E-modulus after 900 s at 110 °C

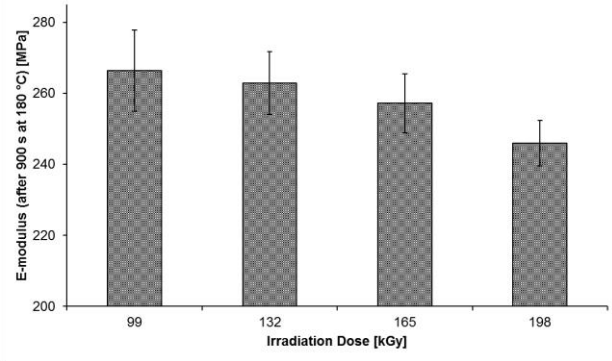

Figure 7. LDPE E-modulus after 900 s at 180 °C

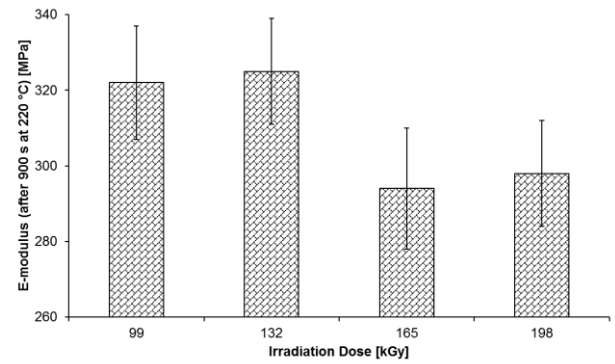

Figure 8. LDPE E-modulus after 900 s at 220 °C

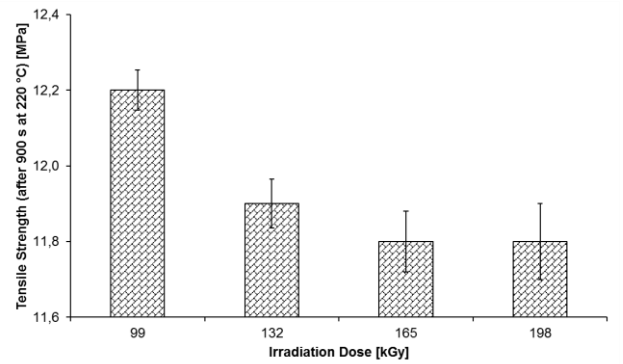

Figure 12. LDPE tensile strength after 900 s at 220 °C

The value of non-irradiated sample tensile strength was measured 11.1 MPa at 23°C. As can be seen in Fig. 9, there was not a significant growth of the tensile strength with increasing doses of irradiation before temperature load.

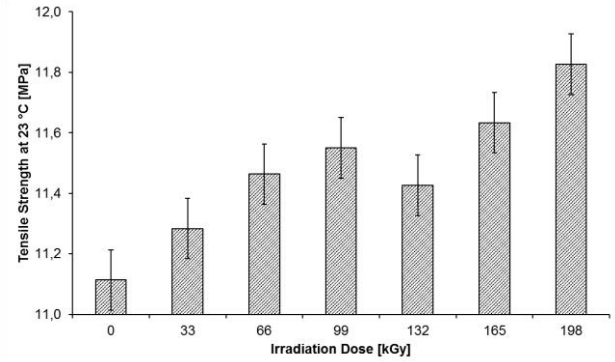

Figure 9. LDPE tensile strength at 23 °C

In the Fig. 10, Fig. 11 and Fig. 12 there are shown values of LDPE tensile strength after temperature load at 110, 180 and 220 °C with time exposition 900 s, respectively.

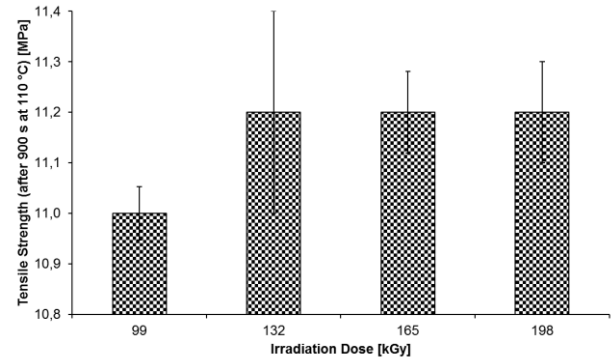

Figure 10. LDPE tensile strength after 900 s at 110 °C

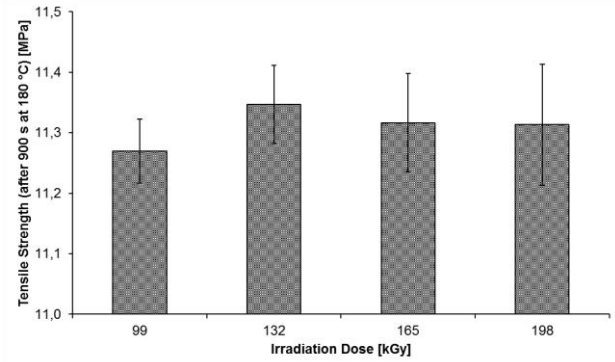

Figure 11. LDPE tensile strength after 900 s at 180 °C

The value of non-irradiated sample elongation at break was measured 145 % at 23°C. As can be seen in Fig. 13, there was a significant increase of the elongation at break with increasing doses of irradiation. The elongation at break rises about 9 % after irradiation with a dosage of 198kGy in comparison with non-irradiated LDPE. The elongation at break after temperature load at 180°C with the same dosage increases about 18 % in comparison with non-irradiated LDPE before temperature load as can be seen in Fig. 15.

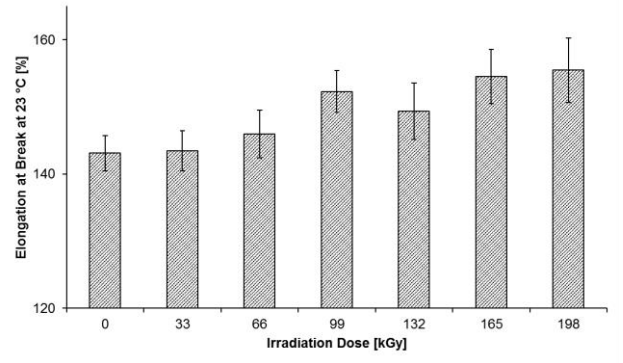

Figure 13. LDPE elongation at break at 23 °C

In the Fig. 14, Fig. 15 and Fig. 16 there are shown values of LDPE elongation at bereak after temperature load at 110, 180 and 220 °C with time exposition 900 s, respectively.

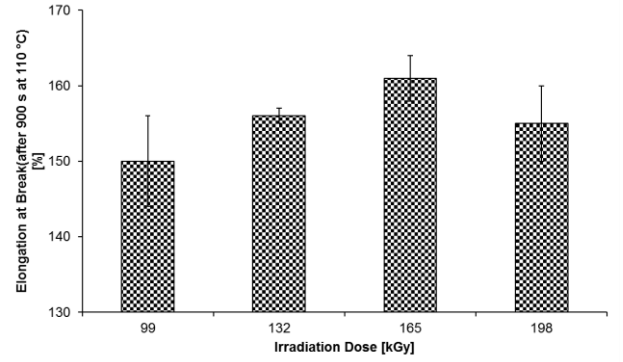

Figure 14. LDPE elongation at break after 900 s at 110 °C

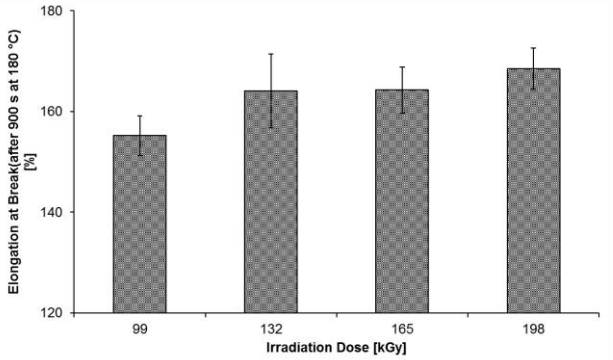

Figure 15. LDPE elongation at break after 900 s at 180 °C

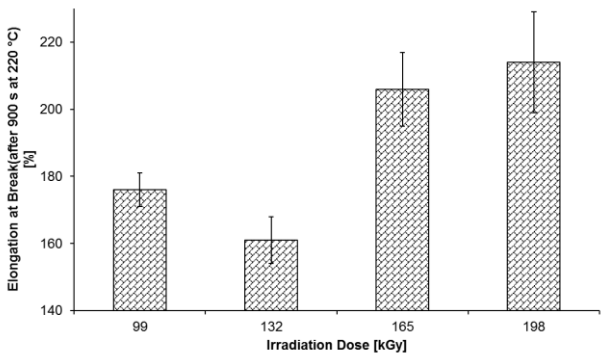

Figure 16. LDPE elongation at break after 900 s at 220 °C

In the Fig. 17 it is possible to see comparison of LDPE E-modulus change before and after temperature load (110, 180 and 220 °C) with exposition 900 s. The most decrease of E-modulus was observed by the LDPE specimen with the dosage of irradiation 132 kGy for temperature loaded LDPE specimen at 110 °C, it is by 35 % decrease. Another temperature loads of LDPE specimens there are not observed as significant decline of E-modulus as by the temperature load at 110 °C.

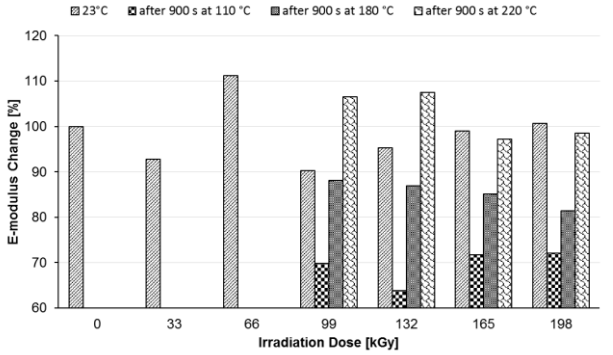

Figure 17. LDPE E-modulus change

In the Fig. 18 it is possible to see comparison of LDPE tensile strength change before and after temperature load (110, 180 and 220 °C) with exposition 900 s. Tensile strength before and after temperature load changes only minimal, except temperature loaded LDPE specimens at 220 °C, there was increase of tensile strength almost 10 % by the LDPE specimen with the dosage of irradiation 99 kGy.

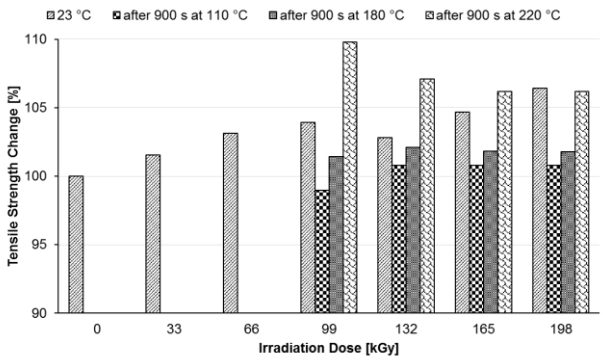

Figure 18. LDPE tensile strength change

In the Fig. 19 it is possible to see comparison of LDPE elongation at break change before and after temperature load (110, 180 and 220 °C) with exposition 900 s. The most rise of elongation at break was observed by the LDPE specimen with the dosage of irradiation 198 kGy for temperature loaded LDPE specimen at 220 °C, it is by 50 % increase. Every modificated by irradiation and temperature loaded specimen has higher elongation at break than non-modificated LDPE specimen (non-irradiated and temperature non-loaded).

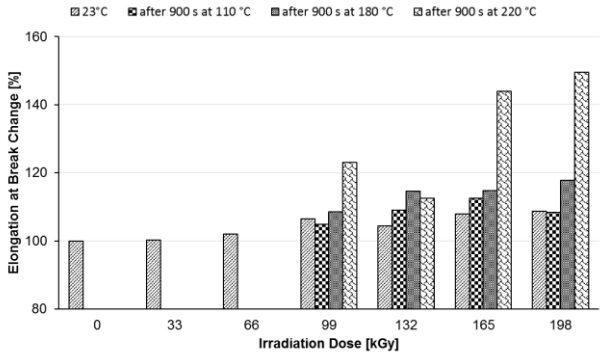

Figure 19. LDPE elongation at break change

4 CONCLUSIONS

Experiments done in this project showed that irradiation cross-linking markedly affected the mechanical and thermo-mechanical properties of the LDPE studied. The higher the irradiation dosage, the better the thermo-mechanical and tensile behaviour of studied polymers is. As can be seen from the tests results, the irradiation cross-linking improves the LDPE tensile behaviour.

Irradiation improves the thermal properties of polymer. Tested polymer (LDPE) shows better temperature stability after irradiation. Irradiation significantly extends the application area of polymers. The service temperature can be higher than the melting point of not irradiated polymers.

The results of the measurements of LDPE after irradiation showed significant changes of its mechanical and thermo-mechanical properties. The E-modulus rises by 8 %, after irradiation with a dosage of 132 kGy after temperature load at 220 °C in comparison of non-modificated sample. The tensile strength is almost constant before and after temperature load. The elongation at break rises by 50 %, after irradiation with a dosage of 198kGy and after temperature load at 220 °C in comparison of non-modificated sample. A very important point is the improvement of the LDPE specimen temperature stability, after irradiation.

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