Strength of Bonded Joints at Elevated Temperatures after Radiation Cross-linking

M. Bednarik, D. Manas, M. Manas, M. Stanek, A. Mizera, M. Ovsik, and P. Kratky

***Abstract*—**In this study there was found that ionizing beta radiation increased the strength of bonded joints and improved the adhesion properties of low-density polypropylene (LDPE) and high-density polyethylene (HDPE). Bonded joints at elevated temperature (60 °C) were tested. Generally, for the formation of quality bonded joint it is important to wet the adhesive bonding surface well. Wettability is characterized by the contact angle of wetting. The liquid has to have a lower surface tension than the solid in order to be able to wet the solid substance. The measurement results indicated that ionizing beta radiation was a very effective tool for improvement of adhesive properties and increased the strength of bonded joints of studied polymers at elevated temperature (60 °C). Bonded surfaces with ionizing beta radiation doses of 0, 66, 132, 165 and 198 kGy were irradiated. The best results were achieved by irradiation at doses of 165 kGy by which the highest surface energy and the highest strength of bonded joints of HDPE and LDPE were achieved.

***Keywords*—**Surface energy, ionizing beta radiation, strength, bonding, adhesion, polymers, elevated temperature

I. Introduction

BONDING has experienced tremendous expansion in the field of joining materials in the last years. Because of that expansion bonding is classed as new techniques even when it is in fact very old. [2, 4]

In comparison with conventional joining methods (riveting, welding and screwing) bonding provides a new combination of options and it allows obtaining special shapes and properties which cannot be created by conventional methods of coupling.

Joining materials using adhesive joints offers several benefits, but also limiting factors if compared with using mechanical joints. To decide about the type of coupling it is necessary to consider the advantages and disadvantages of bonding in comparison with traditional joining technique. Among the advantages of bonding especially belong:

1. We can connect the same and dissimilar materials and do not take into account the thickness.
2. Application of adhesives does not undermine the coherence of the connect parts.
3. Watertight and gastight joints may be prepared.
4. It does not disturb profile or aesthetic appearance of bonded file and does not increase its weight.
5. Joints can be transparent or colored and it is possible to achieve their high strength.
6. The load at the joint interface is distributed over an area rather than concentrated at a point.
7. Joints are more resistant to flexural, fatigue, and vibrational stresses.
8. Bonding is often less expensive and faster than mechanical joining.
9. Can be more easily adapted to join irregular surfaces than mechanical joints.

Adhesive bonding has also several technological disadvantages, in comparison with mechanical joints. The disadvantages of bonded joints are the requirements for planeness and cleanness of surface to be bonded and sensitivity to peel stress. Special surface treatments are required for bonded materials with poor adhesion properties and maximum bond strength is reached after the certain time. [2, 4, 5, 6, 9, 12, 14]

II. Experimental

The aim of the experiment was to examine the effect of beta irradiation on the strength of bonded joints for selected types of materials at elevated temperature (60 °C).

A. Materials

For this experiment low-density polyethylene LDPE DOW – LDPE 780 E and high-density polyethylene HDPE DOW – HDPE 25055E were used.

Low-density polyethylene and high density polyethylene belong to the group of polyolefins. Polyolefins are the largest group of thermoplastics which are often referred to as commodity thermoplastics. Polyolefins consist only of carbon and hydrogen atoms and they are non-aromatic. The two most

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important and common polyolefins are polyethylene and polypropylene which are much exploited for its price accessibility of raw materials, good process ability, and advantageous user properties. Polyolefins are for its non-polar character and low surface energy can not be bonded without previous surface treatment. [15, 16, 19]

Polyolefins are usually processed by extrusion, injection molding, blow molding, and rotational molding methods. Polyethylene is used for the production of packaging materials (shrinkable films, pouches), gear wheels, bearings, textile fibers, and toys. Polyethylene is currently the most widely used polymer in the world. [9, 10, 12, 13]

The samples were made by using the injection molding technology on the injection molding machine Arburg Allrounder 420C (Fig. 1). Injection conditions are shown in Table 1.

Fig. 1 Arburg Allrounder 420C

Table 1 Injection conditions

	HDPE	LDPE
Injection rate	60 mm/s	50 mm/s
Injection pressure	800 bar	600 bar
Injection time	0,4 s	0,4 s
Cooling time	20 s	30 s
Mold temperature	40 °C	40 °C
Holding pressure	600 bar	500 bar
Cycle time	56,8 s	56,6 s
Temperature of zone 2	200 °C	190 °C
Temperature of zone 3	205 °C	200 °C
Temperature of zone 4	210 °C	210 °C
Temperature of zone 5	225 °C	215 °C
Temperature of zone 6	230 °C	220 °C

The samples had the shape and dimensions according to the CSN EN ISO 527 – 2. Before bonding, surfaces of samples were irradiated by ionization beta radiation of doses of 0, 66, 132, 165, and 198kGy at Beta – Gamma Service GmbH & Co. KG, Germany. [3, 6, 7, 10, 11, 14, 17]

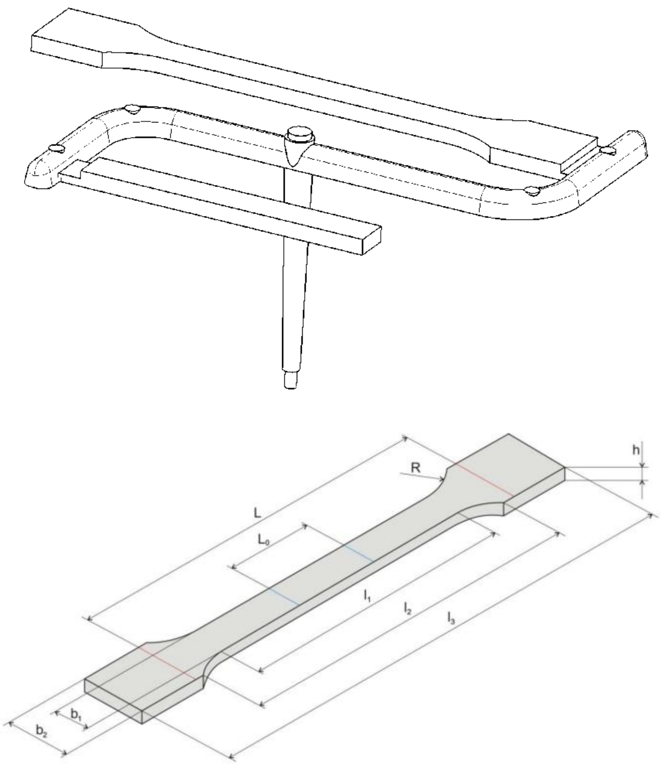

Fig. 2 Testing Specimen [8]

Tab. 2 Specimen dimensions [8]

Test specimen parameters	
b_1 - Width of Gage Length	10 ± 0.2 [mm]
b_2 - Width of Gripping End	20 ± 0.2 [mm]
l_1 - Length of gage Length	80 ± 2 [mm]
l_2 - Distance Between Gripping Ends	104-113 [mm]
l_3 - Specimen Length	≥ 150 [mm]
L_0 - Distance of Extensometers	30 ± 0.5 [mm]
L - Distance of Grips	115 ± 1 [mm]
h - Specimen Thickness	4 ± 0.2 [mm]
R - Radius	20 - 25 [mm]

B. Surface treatment by beta radiation

Ionizing beta radiation gives inexpensive commodity plastics and technical plastics the mechanical, thermal, and chemical properties of high-performance plastics. This upgrading of the plastics enables them to be used in conditions which they would not be able to with stand otherwise. The energy-rich beta rays trigger chemical reactions in the plastics which results in networking of molecules (comparable to the vulcanization of rubbers which has been in industrial use for so long). [1, 3, 7, 8]

The energy from the rays is absorbed by the material and cleavage of chemical bonds takes place. This releases free radicals which in next phase from desired molecular bonds. [3, 8, 14,18, 21]

The irradiation cross-linking of thermoplastic materials via electron beam or cobalt 60 (gamma rays) is performed separately, after processing. Generally, ionizing radiation includes accelerated electrons, gamma rays and X-rays. Radiation processing with an electron beam offers several distinct advantages when compared with other radiation sources, particularly γ-rays and x-rays.

The process is very fast, clean and can be controlled with much precision. There is no permanent radioactivity since the machine can be switched off. In contrast to γ-rays and x-rays, the electron beam can be steered relatively easily, thus allowing irradiation of a variety of physical shapes.

The electron beam radiation process is practically free of waste products and therefore is no serious environmental hazard. These are not only capable of converting monomeric and oligomeric liquids, but also can produce, due to cross-linking, major changes in the properties of solid polymers. The cross-linking level can be adjusted by the irradiation dosage. The absorbed dosage means the value of energy of ionizing radiation absorbed by a unit of mass of the processed material. The unit of absorbed dose is 1 Gray (1 Gy = 1J/kg).

The main difference between beta and gamma rays is in their different abilities to penetrate the irradiated material. Gamma rays have a high penetration capacity. The penetration capacity of electron rays depends on the energy of the accelerated electrons. Due to electron accelerator, the required dosage can be applied within seconds, whereas several hours are required in the gamma radiation plant (Fig. 3). [3, 34, 35, 36, 37-42]

Beta and gamma rays can be used for the irradiation of polyolefines, polyesters, halogen polymers and polyamides from the thermoplastics group, elastomers and thermoplastic elastomers. Some of them need the addition of a cross-linking agent. Polymers can be classified into two groups according to their response to ionizing radiation. One group exhibits predominant cross-linking, the other predominant chain scission. [1, 3, 34, 35, 36]

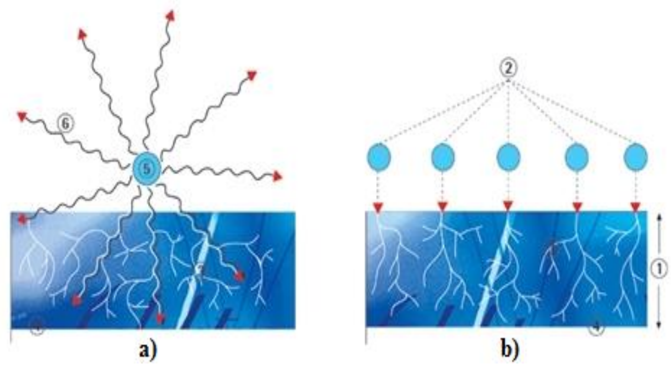

Fig. 3 Design of Gamma Rays (a) and Electron Rays (b) [3]

a) 3 – Secondary electrons, 4 – Irradiated material,
5 – Encapsulated Co – 60 Radiation source, 6 – Gamma rays
b) 1 – Penetration depth of an electron, 2 – Primary electron,
3 –Secondary electron, 4 – Irradiated material

Irradiation cross-linking of thermoplastic materials deals with creation of a cross-link among the macromolecular strings. Intermolecular forces are replaced by a covalent bond. As a result, we can optimise properties of standard and engineering polymers and impart them the properties of high performance polymers (Fig. 4).

Irradiation of polymers turned out to be interesting because of economic reasons, production costs and a life time of products. However, these benefits depend on the type of irradiated polymer and the radiation dosage. Behaviour of each material is different after irradiation. We cannot expect the improvement in all areas (in mechanical, thermal and chemical). Most of polymers are not suitable for irradiation because of degradation and deterioration of their properties. [8, 22-33]

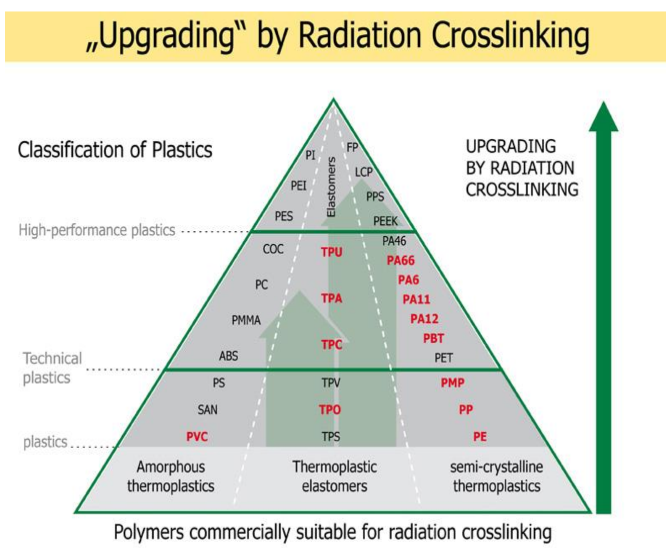

Fig. 4 Pyramid of Polymers [3]

C. *Wetting contact angle measurements*

The angle of contact was measured by using the sessile drop (Fig. 4) and surface energy was determined by OWRK method (Owens – Wendt – Rabel – Kaeble method).

The liquids water, glycerol and ethylene glycol with known γ^p (polar component) and γ^d (dispersive component) were used for calculating the surface energy of HDPE and LDPE. [2, 4, 11]

Table 3 Surface energy of liquids

Liquid	γ_l (mJ/m^2)	γ_l^d (mJ/m^2)	γ_l^p (mJ/m^2)
Distilled water	72.8	21.8	51.0
Glycerol	64.0	34.0	30.0
Ethylene glycol	48.0	29.0	19.0

The height (h) and radius (r) of the liquids were measured by using microscope and the contact angle was calculated using the following equation:

$$\text{contact angle } (\theta) = \frac{\sin^{-1}(2rh)}{(r^2 + h^2)}. \qquad (1)$$

The polar and dispersive components of the surface energy of the polymer surface were calculated using methods OWRK:

$$\frac{(1+\cos\theta)\gamma_l}{2\sqrt{\gamma_l^d}} = \sqrt{\gamma_s^p}\sqrt{\frac{\gamma_l^p}{\gamma_l^d}} + \sqrt{\gamma_s^d}, \qquad (2)$$

where θ is the contact angle of testing liquids, γ_l is the liquid surface energy, and γ_l^p and γ_l^d are the polar and dispersive components of the test liquids. The values of polar and dispersive components of testing liquids are given in Table 1. [2, 11]

Similarly, the solid – surface energy (γ_s) is expressed in terms of its polar and dispersive components:

$$\gamma_s = \gamma_s^p + \gamma_s^d. \qquad (3)$$

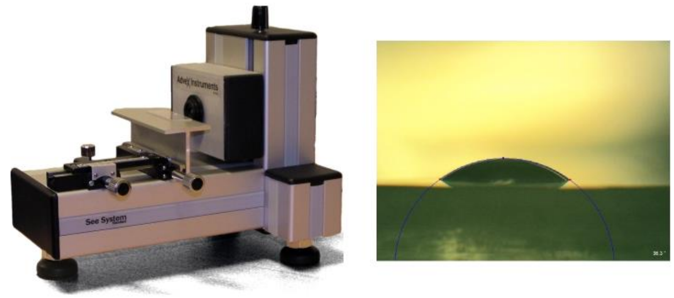

Fig. 4 Surface Energy Evaluation System (See System) [43]

D. *Testing the strength of bonded joints*

After sample preparation (production and irradiation) contact angles were measured and surface energy was calculated. Then the samples were bonded and their strength was measured. For testing the strength of bonded joints there was used a tensile test on the test machine Zwick 1456. Test conditions were according to the CSN EN ISO 527-1 and CSN EN ISO 527-2. Speed was 10 mm/min and evaluation software was Test Expert Standard. [18, 20, 34, 35, 36]

III. Results and Discussion

A. *Contact angle and surface energy*

The variation in contact angle of HDPE for different doses of radiation and for different test liquids is shown in Fig. 1. It shows that the contact angle on the untreated surface is 89.2°, 79.1°, and 66.3° for distilled water, glycerol, and ethylene glycol, respectively. The contact angle values were considerably reduced after irradiation by a dose of 165 kGy to lower values of 57.9°, 54.6°, and 31.1° for distilled water, glycerol, and ethylene glycol, respectively (referring to: Fig. 5).

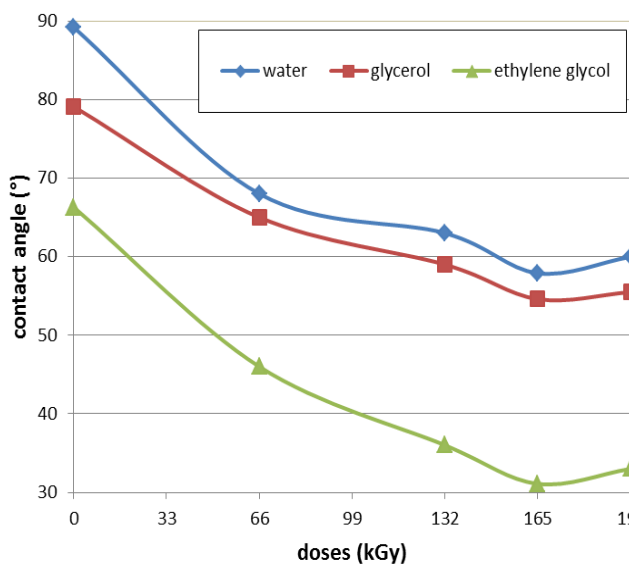

Fig. 5 Variation of contact angle with respect to radiation dose for material HDPE

The variation in contact angle of LDPE for different doses of radiation and for different test liquids is shown in Fig. 2. It shows that the contact angle on the untreated surface is 89.2°, 79.2°, and 67.9° for distilled water, glycerol, and ethylene glycol, respectively (referring to Fig. 6).

The contact angle values were considerably reduced after irradiation by a dose of 165 kGy to lower values of 54.7°, 49.3°, and 36.6° for distilled water, glycerol, and ethylene glycol, respectively (referring to Fig. 6).

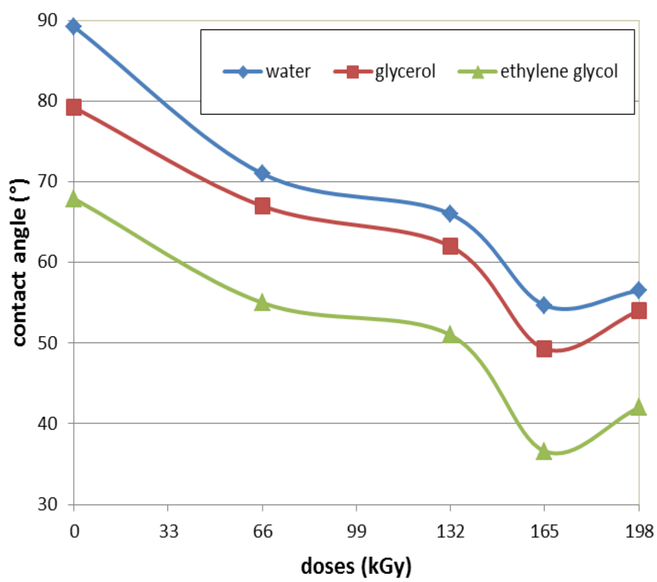

Fig. 6 Variation of contact angle with respect to radiation dose for material LDPE

Fig. 7 shows a plot of surface energy γ_S from the measured contact angles on the surface of the HDPE.

It shows that surface energy of untreated surface is 24.2 mJ/m^2 and 24.5 mJ/m^2 for water + glycerol and water + ethylene glycol, respectively. Ionization beta radiation increases the surface energy. The surface energy values considerably increased after irradiation by a dose of 165 kGy to higher values of 42.6 mJ/m^2 for water + glycerol and 43.1 mJ/m^2 for water + ethylene glycol.

Fig. 8 shows a plot of surface energy γ_S from the measured contact angles on the surface of the LDPE.

It shows that surface energy of untreated surface is 24.1 mJ/m^2 and 23.2 mJ/m^2 for water + glycerol and water + ethylene glycol, respectively. Ionization beta radiation increases the surface energy. The surface energy values considerably increased after irradiation by a dose of 165 kGy to higher values of 45.4 mJ/m^2 for water + glycerol and 45.6 mJ/m^2 for water + ethylene glycol.

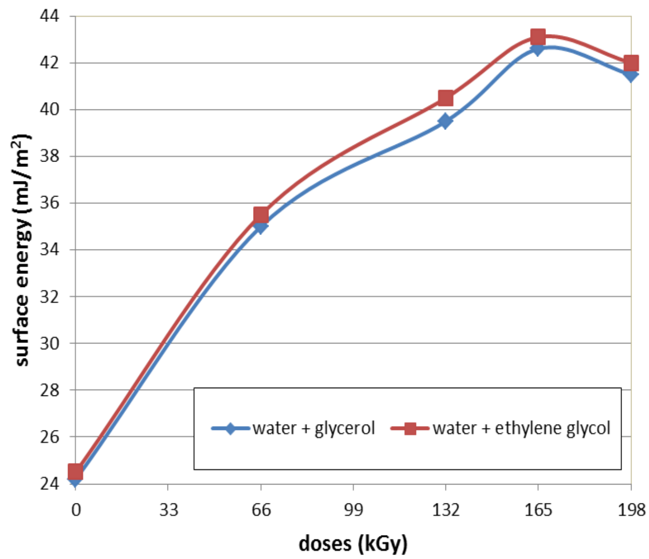

Fig. 7 Variation of surface energy with respect to radiation dose for material HDPE

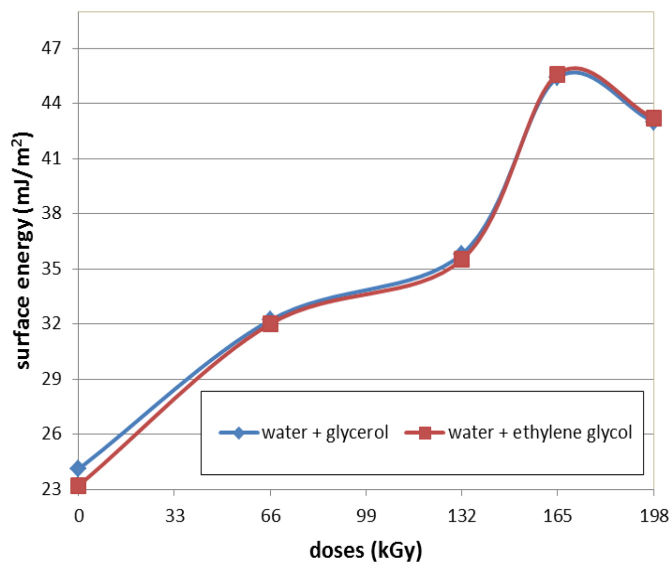

Fig. 8 Variation of surface energy with respect to radiation dose for material LDPE

Similar trend was observed for the polar component γ_S^p (refer with: Fig. 9 and Fig.10). The properties such as wettability, adhesion strongly depends upon the surface energy.

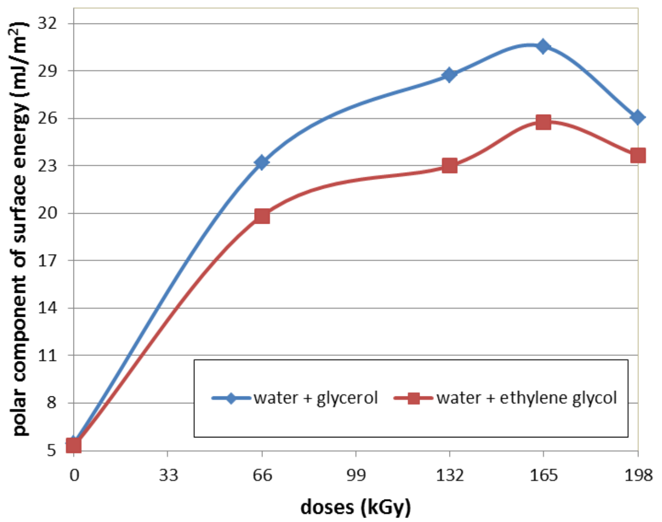

Fig. 9 Variation of polar component of surface energy with respect to radiation dose for material HDPE

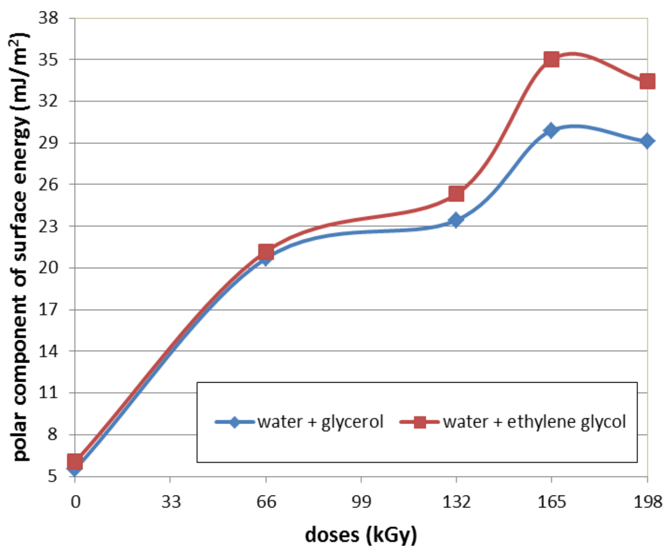

Fig. 10 Variation of polar component of surface energy with respect to radiation dose for material LDPE

B. Strength of bonded joints of HDPE

Strength of bonded joints is characterized by the maximum burdensome force which endured bonded sample. For bonding of HDPE two-component methacrylate adhesive Cyberbond A806, two-component epoxy adhesive Cyberbond E705, and cyanoacrylate adhesive Cybebrond 2008 were used.

The highest strength of bonded joints samples of HDPE (adhesive Cyberbond E705) have those which were irradiated by a dose of 165 kGy. After the irradiation by a dose of 165 kGy strength is increased by 100 % (referring to: Fig. 11).

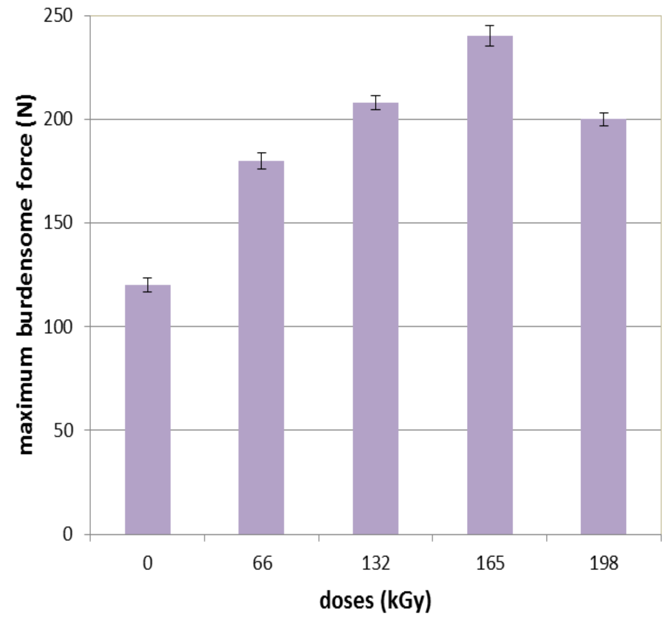

Fig. 11 Variation of strength of bonded joints with respect to radiation dose (material HDPE at 60 °C, adhesive Cyberbond E705)

The highest strength of bonded joints samples of HDPE (adhesive Cyberbond A806) have those which were irradiated by a dose of 165 kGy. After the irradiation by a dose of 165 kGy strength is increased by 180 % (referring to: Fig. 12).

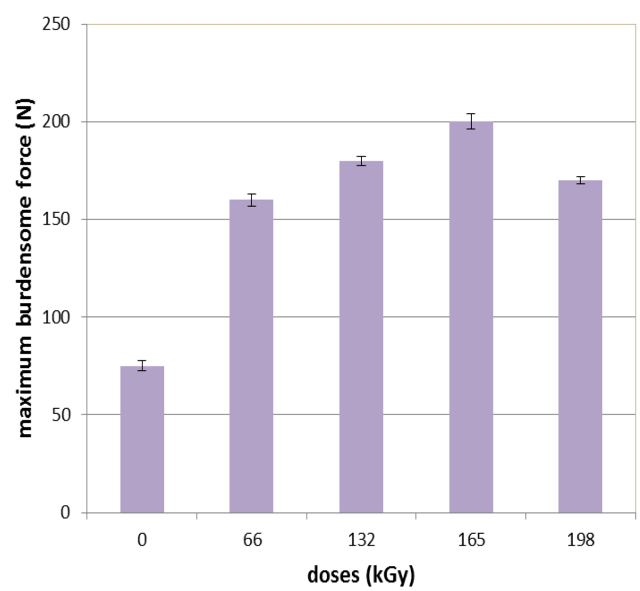

Fig. 12 Variation of strength of bonded joints with respect to radiation dose (material HDPE at 60 °C, adhesive Cyberbond A806)

The highest strength of bonded joints samples of HDPE (adhesive Cyberbond 2008) have those which were irradiated by a dose of 165 kGy. After the irradiation by a dose of 165 kGy strength is increased by 250 % (referring to: Fig. 13).

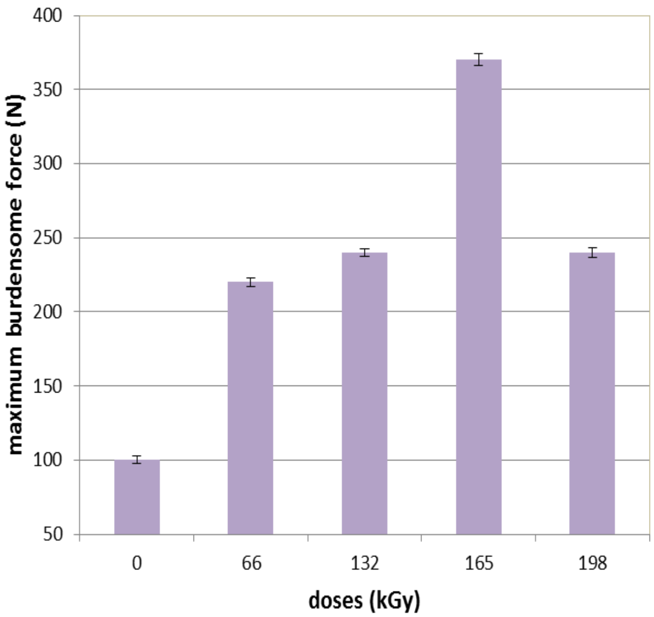

Fig. 13 Variation of strength of bonded joints with respect to radiation dose (material HDPE at 60 °C, adhesive Cyberbond 2008)

C. Strength of bonded joints of LDPE

For bonding of LDPE one type of two-component epoxy adhesive of company Cyberbond (E705) and two types of cyanoacrylate adhesives of companies Cyberbond (2008 and 5008) were used.

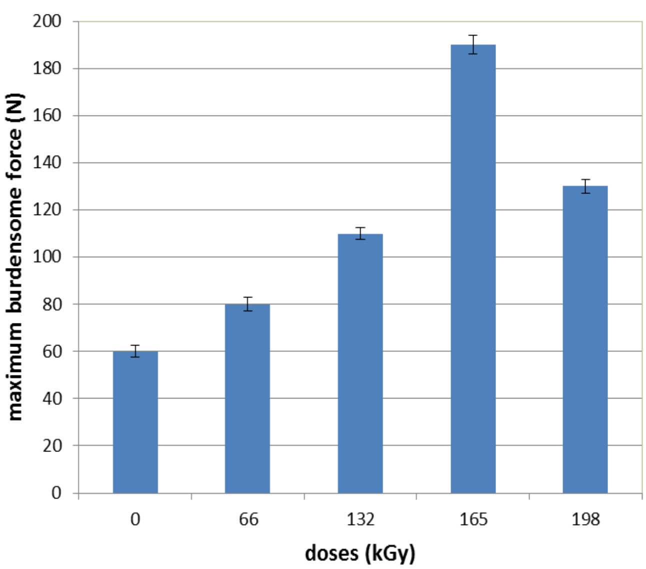

Fig. 14 Variation of strength of bonded joints with respect to radiation dose (material LDPE at 60 °C, adhesive Cyberbond E705)

The highest strength of bonded joints samples of LDPE (adhesive Cyberbond E705) have those which were irradiated by a dose of 165 kGy. After the irradiation by a dose of 165 kGy strength is increased by 200 % (referring to: Fig. 14).

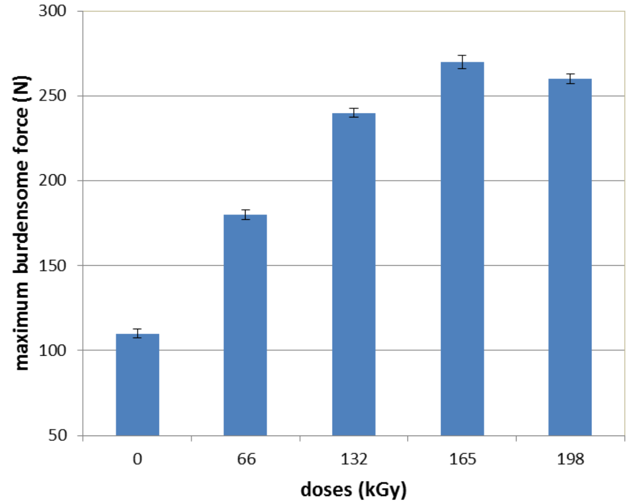

Fig. 15 Variation of strength of bonded joints with respect to radiation dose (material LDPE at 60 °C, adhesive Cyberbond 2008)

The highest strength of bonded joints samples of LDPE (adhesive Cyberbond 2008) have those which were irradiated by a dose of 165 kGy. After the irradiation by a dose of 165 kGy strength is increased by 150 % (referring to: Fig. 15).

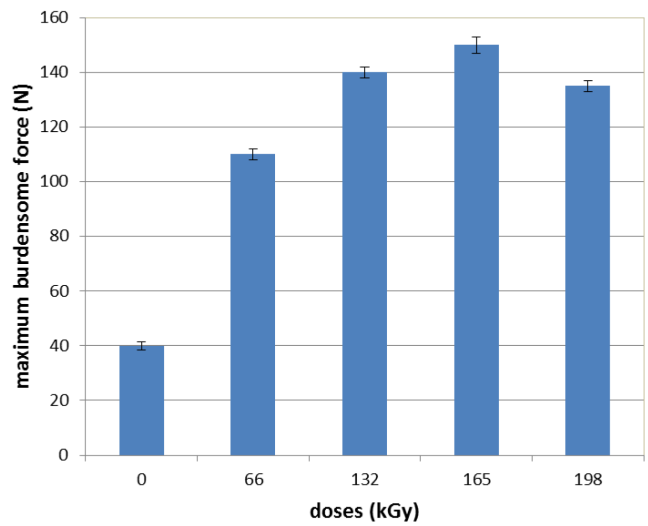

Fig. 16 Variation of strength of bonded joints with respect to radiation dose (material LDPE at 60 °C, adhesive Cyberbond 5008)

The highest strength of bonded joints samples of LDPE (adhesive Cyberbond 5008) have those which were irradiated by a dose of 165 kGy. After the irradiation by a dose of 165 kGy strength is increased by 350 % (referring to: Fig. 16).

IV. CONCLUSION

This article describes the effect of beta radiation on the contact angle of wetting, on the surface energy and on the final strength of bonded joints of HDPE and LDPE (at 60 °C). Beta radiation increases the strength of bonded joints of HDPE and LDPE and improves their adhesion properties. The best results were achieved by irradiation at doses of 165 kGy by which the highest surface energy and the highest strength of bonded joints of HDPE and LDPE were achieved.

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REFERENCES

[1] Drobny, J.G., *Radiation Technology for Polymers*, Boca Raton: CRC Press, 2003, ISBN 1-58716-108-7.

[2] Lapcikovs, B., Lapcik, L., Smolka, P., Dlabaja, R. and Hui, D. (2006), *Application of radio frequency glow discharge plasma for enhancing adhesion bonds in polymer/polymer joints.* J. Appl. Polym. Sci., 102: 1827–1833. doi: 10.1002/app.24081.

[3] BGS – Beta Gama Service. [online]. www: <http://bgs.eu>

[4] Drobny, J.G., *Handbook of Thermoplastic Elastomers* ,William Andrew Publishing, Norwich,NY,2007, ISBN: 978-0-8155-1549-4

[5] Brocka, Z., *Werkstoff- und Einsatzpotential strahlenvernetzter Thermoplaste,* Lehrsthul für Kunststofftechnik (LKT), Nürnberg, 2008.

[6] Woods, R. J., *Applied radiation chemistry: radiation processing,* A Wiley-Interscience publication, New York, 1994, ISBN 0-471-54452-3.

[7] Manas, M., Stanek, M., Manas, D. at all: *Temperature stability of irradiated polymers*. Chemickelisty, 105(S), p254-256, ISSN 0009-2770.

[8] Holik, Z., Danek, M., Manas, M., at all: Chemickelisty, 105(S), p269-271, ISSN 0009-2770.

[9] M. Stanek et al., Optimization of Injection molding process, *International Journal of Mathematics and Computers in Simulation*, Vol.5, 2011, pp. 413-421.

[10] M. Stanek et al., Simulation of Injection Molding Process by Cadmould Rubber, *International Journal of Mathematics and Computers in Simulation*, Vol.5, 2011, pp. 422-429.

[11] D. Manas et al., *Thermal Effects on Steels at Different Methods of Separation*, ChemickeListy, Vol.105, 2011, pp. 713-715.

[12] M. Manas et al., *Improvement of Mechanical Properties of the TPE by Irradiation*, ChemickeListy, Vol.105, 2011, pp. 828-829.

[13] M. Stanek et al., *Influence of Surface Roughness on Fluidity of Thermoplastics Materials*, ChemickeListy, Vol.103, 2009, pp. 91-95.

[14] D. Manas et al., *Influence of Mechanical Properties on Wear of Heavily Stressed Rubber Parts, KGK – KautschukGummiKunststoffe*, Vol.62, 2009, pp. 240-245.

[15] M. Manas et al., *Modification of Polyamides Properties by Irradiation*, ChemickeListy, Vol.103, 2009, pp. 24-26.

[16] D. Manas et al., *Wear of Multipurpose Tire Treads*, ChemickeListy, Vol.103, 2009, pp. 72-74.

[17] S. Sanda et al., *Injection Mold Cooling System by DMLS*, ChemickeListy, Vol.103, 2009, pp. 140-142.

[18] S. Sanda et al., *Gate Effect on Quality of Injected Part*, ChemickeListy, Vol.105, 2011, pp. 301-303.

[19] M. Stanek et al., *How the Filler Influence the Fluidity of Polymer*, ChemickeListy, Vol.105, 2011, pp. 303-305.

[20] V. Pata et al., *Visualization of the Wear Test of Rubber Materials*, ChemickeListy, Vol.105, 2011, pp. 290-292.

[21] D. Maňas, M. Maňas, M. Stanek, T. Drga, *Influence of Radiation on Polymer Properties,* Chemickelisty, Vol. 101, 2007, pp. 27-28.

[22] M. Stanek, M. Manas, T. Drga, D. Manas, "Testing Injection Molds for Polymer Fluidity Evaluation", *17th DAAAM International Symposium: Intelligent Manufacturing* & *Automation: Focus on Mechatronics and Robotics*, Vienna, Austria, 2006, p.397-398.

[23] S. Sanda et al., *Injection Mold Cooling System by DMLS*, Chemicke Listy, Vol.103, 2009, pp. 140-142.

[24] V. Pata et al., *Visualization of the Wear Test of Rubber Materials*, Chemicke Listy, Vol.105, 2011, pp. 290-292.

[25] K. Kyas, M. Stanek, Manas, M. Stanek, M. Krumal, Z. Holik, *Simulation of ruber injection holding process*, 2011, Chemicke listy, Volume 105, Issue 15, pp. S354-S356

[26] J. Javorik et al., The Shape Optimization of the Pneumatic Valve Diaphragms, *International Journal of Mathematics and Computers in Simulation*, Vol.5, 2011, pp. 361-369.

[27] Ovsik, M. – Manas, D. – Stanek, M. – Manas, M. – Cerny, J. – Bednarik, M. – Mizera, A.: Microhardness of Modified Thermoplastics, Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium, 23-26th November 2011, Vienna, Austria, ISSN 1726-9679, ISBN 978-3-901509-83-4, p. 1187-1188, Published by DAAAM International Vienna, Vienna

[28] Navtatil, J. – Stanek, M. – Manas, M. – Manas, D. – Bednarik, M. – Mizera, A.: Utilization of DMLS in Injestion Mold Design, Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium, 23-26th November 2011, Vienna, Austria, ISSN 1726-9679, ISBN 978-3-901509-83-4, p. 1507-1508, Published by DAAAM International Vienna, Vienna

[29] J. Javorik, M. Stanek, "The Numerical Simulation of the Rubber Diaphragm Behavior," *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, Lanzarote, Spain, 2011, pp. 117-120.

[30] J. Javorik, D. Manas, "The Specimen Optimization for the Equibiaxial Test of Elastomers," *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, Lanzarote, Spain, 2011, pp. 121-124.

[31] HOLÍK, Z. - MAŇAS, M. – DANĚK, M. – MACOUREK, J. :Improvement of Mechanical and Thermomechanical Properties of Polyethylene by Irradiation Crosslinking. Chemické listy. Volume 103, 2009, s.60-63, ISSN 0009-2770 (IF: 0,593 MF: 1,256)

[32] CERNY, J. – MANAS, D. – HOLIK, Z. – OVSIK, M. – BEDNARIK, M. – MIZERA, A. – STANEK, M. – MANAS, M.: Wear of Heavy Industry Tires, *International Journal of Mathematics and Computers in Simulation – Issue 1, Volume 7,* ISSN 1998-0159, pp. 9-16, 2013

[33] CERNY, J. – MANAS, D. – HOLIK, Z. – OVSIK, M. – BEDNARIK, M. – MIZERA, A. – MANAS, M. – STANEK, M.: Methods of Design of Ergonomics Parts, *International Journal of Mathematics and Computers in Simulation – Issue 1, Volume 7,* ISSN 1998-0159, pp. 17-24, 2013

[34] MIZERA, A. – MANAS, M. – HOLIK, Z. – MANAS, D. – STANEK, M. – CERNY, J. – BEDNARIK, M. – OVSIK, M.: Properties of HDPE after Radiation Cross-linking, *International Journal of Mathematics and Computers in Simulation – Issue 6, Volume 6*, ISSN 1998-0159, pp. 584-591, 2012

[35] Z. Holik, M. Danek, M. Manas, J. Cerny, "The Influence of Cross-linking Agent on Mechanical Properties of Polyamide Modified by Irradiation Cross-linking", *in Proc. 13th WSEAS International Conference on Automatic Control, Modelling & Simulation*, Lanzarote, Spain, 2011, pp.222-225.

[36] Z. Holik, K. Kyas, M. Krumal, J. Cerny, M. Danek, "Improvement of Polypropylene Properties", *21st International DAAAM Symposium*, 2010, Zadar, Croatia, p. 1191-1192.

[37] H. Vaskova, V. Kresalek, „Raman Spectroscopy of Epoxy Resin Crosslinking", *in Proc. 13th WSEAS International Conference on Automatic Control*, Modelling & Simulation, Lanzarote, Canary Islands 2011, p.357-360.

[38] D. Manas et al., *Wear of Multipurpose Tire Treads*, Chemicke Listy, Vol.103, 2009, pp. 72-74.

[39] D. Manas, M. Stanek, M. Manas, "Workability and Wear of Rubber Parts", Chapter 54 in DAAAM International Scientific Book 2007, Published by DAAAM International, DAAAM International, Vienna, Austria, p.611-626

[40] M. Stanek et al., *Influence of Surface Roughness on Fluidity of Thermoplastics Materials*, Chemicke Listy, Vol.103, 2009, pp. 91-95.

[41] M. Stanek et al., *Plastics Parts Design Supported by Reverse Engineering and Rapid Prototyping*, Chemicke Listy, Vol.103, 2009, pp. 88-91.

[42] M. Stanek et al., *How the Filler Influence the Fluidity of Polymer*, Chemicke Listy, Vol.105, 2011, pp. 303-305.

[43] Advex Instruments. [online]. http://www.advex-instruments.cz