Papers submitted to the Conference "Applications of Physics in Mechanical and Material Engineering"

Determination of the Influence of Irradiation on Physical and Structural Properties of UHMWPE

M. Nabrdalik* and M. Sobociński

Czestochowa University of Technology, 42-201 Czestochowa, Poland

Doi: 10.12693/APhysPolA.142.104 *e-mail: marcin.nabrdalik@pcz.pl

The degradation process of UHMWPE polyethylene in in vitro conditions under the influence of X-rays was assessed. For the tests, the samples were submitted to the radiation dosages of 90, 120, and 150 cGy. The use of copper screening and the use of so-called water phantom made it possible to create samples of irradiation conditions similar to those occurring in the human body at a depth of 4 cm in soft tissues. The differential scanning calorimetry method was used for test on the degree of crystallinity in UHMWPE samples. The test also included friction–wear tests aimed at defining the influence of irradiation dosage on the wear of UHMWPE. The tests were conducted on the T-05 simulator. For the tested models, no significant changes were detected.

topics: UHMWPE, irradiation, wear, degree of crystallinity

1. Introduction

The suitability of polymers like UHMWPE polyethylene for endoprosthesis elements depends on the influence of environmental features and the sterilisation processing. Many publications have raised the issue of radioisotope thermoelectric generator (RTG) radiation and its adverse effect on the properties of polyethylene [1–5].

The surroundings in which the implant operates significantly influence its parts made of UHMWPE polyethylene, causing the implant to degrade. It is very important that the patient, to whom the endoprosthesis is to be implanted, undergoes multiple and various dosages of irradiation during diagnostics procedures. By using various modifications of polyethylene, such as stabilising additives, plasticisers, or by changing the basic components of the polymer, the resistance of the material to these unfavourable factors is increased. Many physico–chemical changes take place in polymers exposed to ionizing radiation, resulting in a change of the material properties [6–8]. The main directions of research related to the irradiation process are narrowed down to the following issues:

- changes in the morphological structure of the polymer;
- changes of various properties of the material;
- the formation of radicals, macro radicals, causing chemical changes in the polymer;
- absorption of radiation energy by the polymer [9–12].

2. Determination of the influence of irradiation on UHMWPE

As part of the work, friction and wear tests were carried out to demonstrate the effect of X-ray dose radiation on the consumption of UHMWPE polyethylene. The tests were conducted on the simulator T-05. The scheme of friction node and the shape and dimensions of the samples are presented, respectively, in Figs. 1 and 2 [13].

The samples (bush halves) were made of Chirulen 1020 [14] polyethylene and the counter-samples (rings) were made of the CoCrMo alloy. The adapted layout imitates the most popular solution applied in friction nodes of endoprostheses [15]. The basic parameters of the test were:

- friction path $S = 20000$ m;
- load on the friction node $P = 600$ N;
- unit pressure $p = 6$ N/mm^2;
- friction surface $F = 1$ cm^2;
- speed–length ratio $V = 0.1$ m/s;
- lubricating medium — Ringer's liquid.

Polyethylene samples were subjected to irradiation at the following exposure parameters:

- source-to-detector distance SSD = 40 cm,
- X-Ray tube voltage U = 200 kV;
- 0.5 mm Cu filter;
- tube current $I = 20$ mA;
- field $S = 100$ cm^2;
- dosage rate $D_{st} = 92.37$ cGy/min.

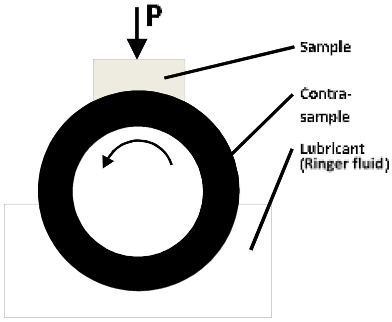

Fig. 1. Scheme of friction node of the simulator T-05.

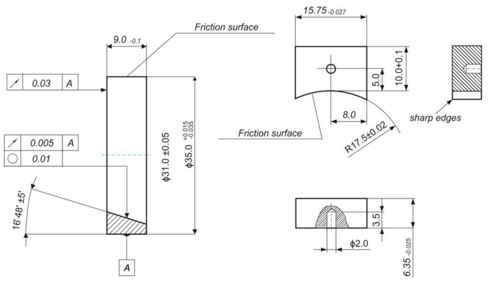

Fig. 2. Shape and dimensions of samples [13].

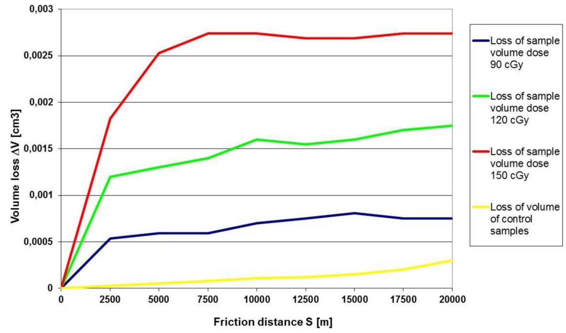

Fig. 3. The influence of exposure to irradiation on friction loss of UHMWPE samples operating with counter-sample made of the CoCrMo alloy.

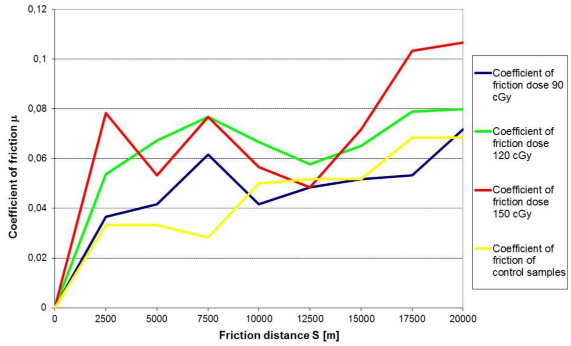

Fig. 4. Relation of the friction coefficient and the friction distance for various exposures.

Three variants of parameters of sample exposure were considered in this work, i.e, (i) D = 90 cGy, T_1 = 0.63 min, (ii) D = 120 cGy, T_2 = 0.83 min, and (iii) D = 150 cGy, T_3 = 1.05 min. Here D is the dose and T is the exposure time.

It should be mentioned that the use of copper shielding and the use of so-called water phantom, allowed the creation of irradiation conditions for samples similar to those that occur in the human body at a depth of 4 cm in soft tissues.

The results of the samples wear after various doses of exposure were presented in Fig. 3.

Figure 4 presents the change of friction coefficient as a friction distance function.

The highest loss appeared in the UHMWPE samples subjected to a dose 150 cGy. Those subjected to lower doses were characterized by lower wear. As presumed, increasing the irradiation dose caused significantly higher wear of polyethylene. All the irradiated UHMWPE samples presented higher wear than those that had not been submitted to X-rays at all. For comparison, a wear curve of a control samples is plotted.

The table of volume loss of polyethylene samples on friction distance S = 10000 m is presented in Fig. 5.

Mating between the friction pairs irradiated UHMWPE–CoCrMo showed similar friction coefficient. i.e., μ = 0.04–0.08.

As far as frictional resistance is concerned, the sample of UHMWPE irradiated with 150 cGy dose, operating with CoCrMo, also showed the highest value. The samples exposed to the doses of 120 and 90 cGy showed a lower friction coefficient when operating with a metal counter-sample.

Characteristic of the irradiated samples is a large number of wear products that could be visually noticeable in the lubricating liquid. The analysis of volume and the quality of wear products will be the subject of a separate publication.

According to literature sources [16, 17], crosslinking of UHMWPE under irradiation occurs mostly in amorphous areas. In the crystallinity areas, the radicals migrate up to the surface of the crystal grains, where they merge together, creating a cross-linked structure.

The samples of UHMWPE exposed to irradiation have been tested for a change of the crystallinity degree. The test has been conducted by using the method of differential scanning calorimetry (DSC). The material for tests was taken out of the irradiated samples with the use of a microtome. Figure 6 presents the table of the results of the crystallinity degree affected by radiation exposure.

Based on the tests, it can be concluded that the difference between the crystallinity degree of the sample which absorbed a dose of 90 cGy (Fig. 6, lower column) and the sample that absorbed 150 cGy (Fig. 6, higher column) is approximately 5%. A similar difference in the crystallinity

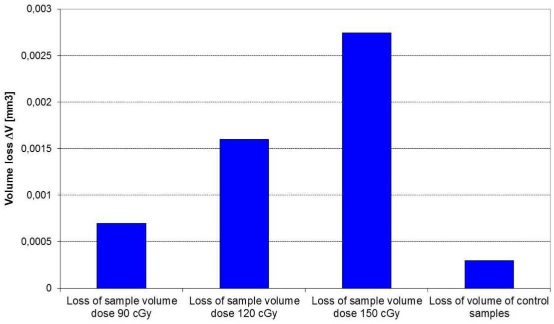

Fig. 5. Volume loss of polyethylene samples after friction distance $S = 10\,000$ m.

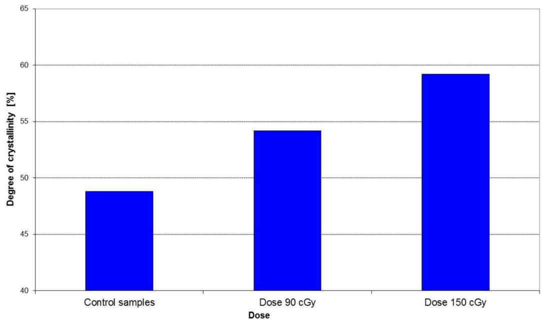

Fig. 6. Crystallinity degree of the chosen samples.

degree (5.4%) has been noticed between the sample not exposed at all and sample which absorbed 90 cGy. These observations prove that by the irradiation dose, the higher the degree of crystallinity of UHMWPE is. The increase is ≈ 5% on for every 60 cGy of dose absorbed.

3. Conclusions

1. Along with the increase in irradiation dose, the volume loss of polyethylene grows, which is clearly observed in the tested control samples.
2. In the case of friction resistance, the highest value had a sample of UHMWPE exposed to the highest radiation. As the irradiation dose increased, the friction resistance increased.
3. The higher the absorbed dose is, the higher the crystallinity degree of UHMWPE is.
4. In future studies, the friction wear tests of polyethylene UHMW should be carried out using a special hip and knee simulators that reflect the operating conditions of the endoprosthesis.
5. Subsequently, the focus should be on the modification of polyethylene allowing for the increase of tribological properties, including wear resistance.

References

[1] P. Sahoo, S. Kalyan Das, J.P. Davim, in: *Woodhead Publishing Series in Biomaterials*, Woodhead Publishing, p. 1, 2019.
[2] N. Stojilovic, S.V. Dordevic, S. Stojadinovic, *Nucl. Instrum. Methods Phys. Res. B* **410**, 139 (2017).
[3] E.M. Ivankova, M. Krumova, L.P. Myasnikova, V.A. Marikhin, G.H. Michler, *Polymer* **47**, 5623 (2006).
[4] S. Gürgen, *Polym. Degrad. Stab.* **199**, 109912 (2022).
[5] J. Quan, H. Wang, J. Yu, *Compos. Sci. Technol.* **201**, 108500 (2021).
[6] J.V. Hamilton., M.B. Schmidt, K.W. Greer, *Radiat. Phys. Chem.* **52**, 283 (1998).
[7] L. Kwon-Yong, L. Keun Ho, *Wear* **225–229**, 728 (1999).
[8] L. Pruitt, R. Ranganathan, *Mater. Sci. Eng.* **C3**, 91 (1995).
[9] M. Gierzyńska-Dolna, M. Sobociński, W. Więckowski, B. Rajchel, *Acta Bioeng. Biomech.* **2**, 197 (2000).
[10] B. Kostrzewa, D. Szewieczek, *Inż. Mater.* **2/1999**, 82 (1999) (in Polish).
[11] M. Podrez-Radziszewska, W. Dudziński, *Materiały X Seminarium Tworzywa Sztuczne w Budowie Maszyn*, 2003, p. 303 (in Polish).
[12] L. Pruitt, R. Ranganathan, *Mater. Sci. Eng.* **C3**, 91 (1995).
[13] Technical Drawing of the Sample (in Polish).
[14] MediTECH, Chirulen 1020, Compression Molded Form Data Sheet.
[15] J. Marciniak. *Biomaterials*, Publishing of Silesian University of Technology, Gliwice 2002.
[16] J. Czupryńska, *Polimery* **47**, 1 (2002).
[17] J. Otwinowski, A. Pawelec, *Pol. Othop. Traumatol.*, **LIX**, 283 (1994).