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Electron beam absorption in 3D-printed polymer samples with different infill densities

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Abstract. In this work, we study the efficiency of electron absorption by the plastic samples produced using 3D printing with different infill densities. We investigate the influence of the print layer orientation relative to the electron beam axis on the radiation dose distribution. It is possible to produce plastic samples with different infill by fused deposition modelling. Ten polymer test samples with the infill density ranging from 10% to 100% are printed and studied experimentally using a 6 MeV electron beam of an MIB-6E betatron. GafChromic EBT3 films are used for the dose measurement. When the infill is above 70%, the difference of dose distribution uniformity cannot be distinguished for the two print layer orientations. Therefore, these samples can be used for electron beam formation.

1. Introduction

Intraoperative radiation with high-energy electron beams is a widely used therapy involving single high radiation dose delivery [1, 2]. During these procedures, it is necessary to form a complex radiation field to affect the tumors located close to critical organs.

In practice, when conducting sessions of electron intraoperative radiotherapy, additional filters are used to reduce the dose load. These filters are installed along the beam path to shift the volume dose distribution in the patient's body closer to the surface. Alternatively, additional blocks can be placed in the tissues under the tumor, which requires a surgical intervention [3]. A method for fast and accurate manufacturing of complex shaped patient-specific samples designed to form electron beams can improve the efficiency of these approaches. Rapid prototyping can be used to develop this method [4, 5].

One of the features of the samples manufacturing by 3D printing is the opportunity to change the filling density of the sample. When producing forming elements, it is necessary to optimize the printing process in order to reduce the time and material consumption and to avoid defects like delamination and deformation of the final sample while ensuring the electron absorption efficiency. Reducing the sample infill usually eliminates the aforementioned problems, but the low density of the absorbers significantly weakens the absorption of high-energy electrons.

In this work, we study the efficiency of the electron absorption by 3D printed plastic samples with different infill densities.

2. Materials and methods

2.1. Polymer test samples

As known, different infill densities can be used to produce plastic samples by fused deposition modelling. [4]. Ten polymer test samples with infill densities ranging from 10 to 100% are printed and studied experimentally. The 2×2×2 cm^3 samples are produced from SBS plastic (styrene-butadiene-styrene) [6].

The test samples are produced using a Prism Pro rapid prototyping unit [7]. The printing is performed with the following parameters: filament diameter is 1.75 mm, layer thickness is 0.3 mm, extruder nozzle diameter is 0.4 mm, speed of printing is 80 mm/minute, and shell thickness is 1.5 mm. Fig. 1 shows the photos of test samples.

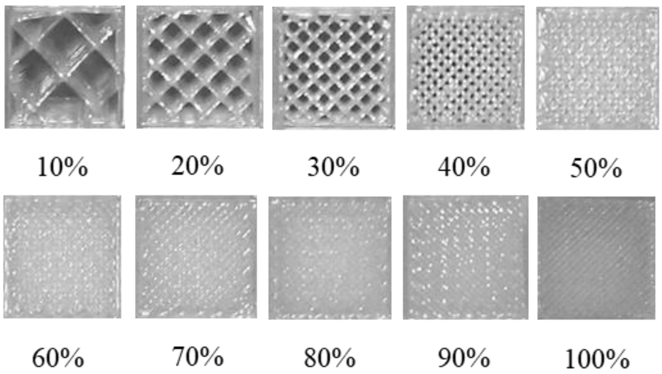

Figure 1. Appearance of plastic test samples.

2.2. Dosimetry equipment

Pre-calibrated polymer films of GafChromic EBT3 [8] are used as a detector. Dosimetry films are located in a tissue-equivalent dosimetry phantom SP34 during the calibration [9]. To control the dose, we use a PTW UNIDOS E dosimeter with a plane-parallel ionization chamber Marcus Chamber Type 23343 [10, 11]. A color flatbed scanner Epson Perfection V750 Pro is used to digitize the dosimetry film [12].

2.3. Experimental set-up

The electron beam of an MIB-6E betatron is used for the experimental investigation [13]. 6-MeV electron beam dose distributions are observed for elliptic applicator of 8×12 cm^2. Samples are placed on the dosimetry film located on the surface of the SP34 phantom [9]. The exit window of the accelerator is 90 cm away from the surface of the tissue-equivalent phantom, while the distance from the edge of the applicator to the surface of the phantom is 5 cm. Fig. 2 shows the experimental geometry.

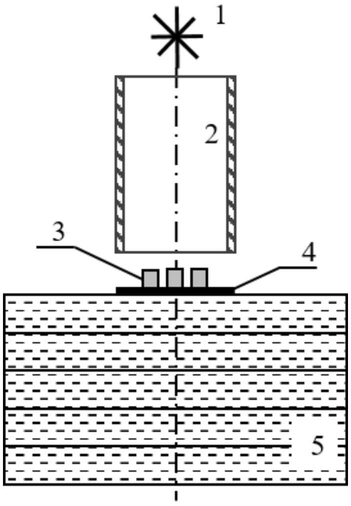

Figure 2. Experimental geometry:1 – source (E_e=6 MeV); 2 – collimating system and aluminum applicator (field size 8×12 cm); 3 – polymer test samples, 4 – dosimetry film; 5 – dosimetry phantom.

In this research, we investigate the electron beam propagation through the samples with transverse (XY) and in-plane (ZX) orientations relative to the beam axis. Fig.3 illustrates the sample orientations.

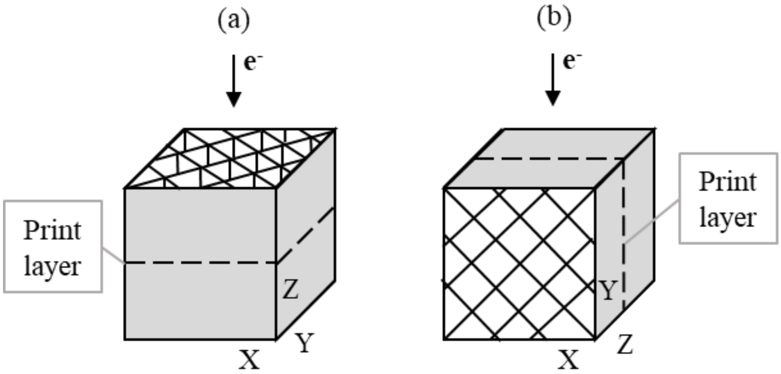

Figure 3. Sample orientations in the experiment:(a) – XY orientation, (b) – ZX orientation.

3. Results and discussions

In this work, we obtain the dose distributions of electron radiation fields behind the plastic samples with different infill densities and different orientations. Fig. 4 presents the dose measurements of the electron beam after passing the samples with infill densities ranging from 10% to 60% in two different orientations.

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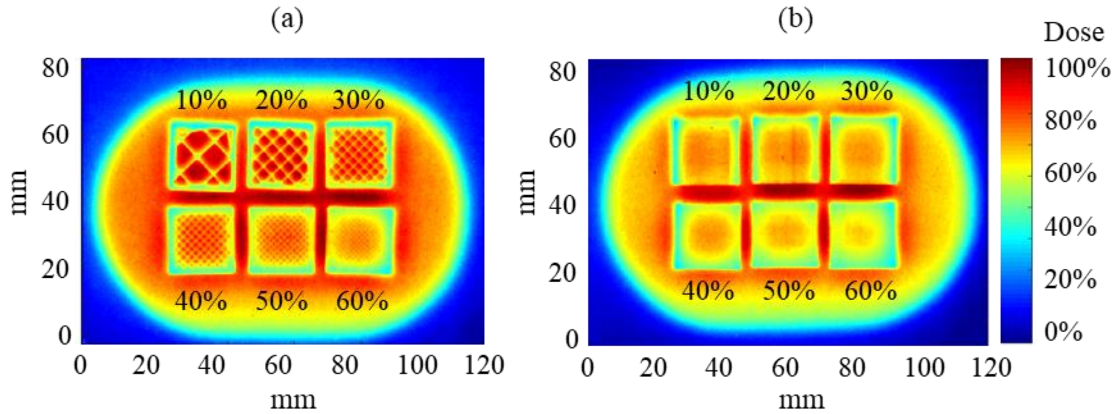

Figure 4. Results of electron beam dose measurements behind the samples with infill densities from 10% to 60%:(a) – XY orientation, (b) – ZX orientation.

Fig.4 demonstrates that for the samples with infill densities ranging from 10% to 60% and XY orientation, the internal structure of the sample is clearly visible, in contrast to ZX orientation. The latter is caused by the electron scattering on internal partitions as well as electron absorption and scattering on the external homogeneous surface of the object.

When the samples with 10% to 60% infill densities are arranged in the XY orientation (Fig. 4,*a*), a non-uniform dose field is formed, which makes this orientation unsuitable for the electron beam formation. The ZX orientation, however, (Fig. 4,*b*) does not have these disadvantages.

Fig. 5 shows the electron beam doses measured after the beam passes the samples with infill densities from 70% to 100% in different orientations.

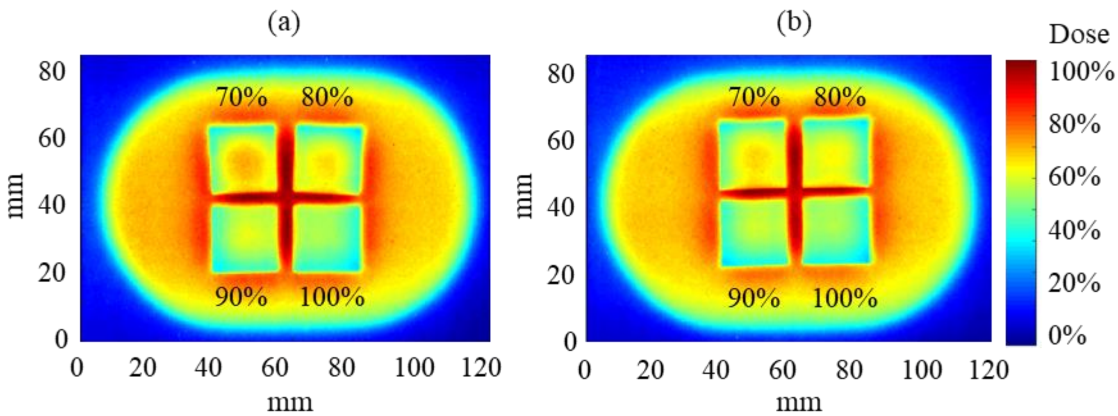

Figure 5. Electron beam doses measured behind the samples with infill densities from 70% to 100%: (a) – XY orientation, (b) – ZX orientation.

Fig. 5 illustrates that for samples with an infill density of more than 70%, the orientation relative to the beam does not affect the uniformity of the dose distribution. However, it can be seen that an increase in the sample infill density during printing leads to a decrease in the dose behind it.

4. Conclusion

The research findings show that the electron beam absorption efficiency of 3D printed plastic samples with an infill density of less than 70% strongly depends on the print layer orientation. The propagation of the electron beam in the transverse print layer orientation is characterized by the heterogeneous distribution of the dose field caused by the peculiarities of the plastic structure. This effect is not observed for the in-plane print layer orientation of the sample.

It is demonstrated that the print layer orientation relatively to the beam propagation axis does not affect the uniformity of the dose distribution when the infill density of the sample is more than 70%.

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The results obtained in this work allow us to conclude that 3D printed plastic samples with a 70% or higher infill density are suitable for the electron field formation in both orientations under study. For the samples printed with infill densities of less than 70%, transverse orientation is impractical for the tasks of electron beam formation.

Acknowledgments
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References
[1] Beddar A, Biggs P, Chang S, Ezzell G, Faddegon B, Hensley F and Mills M 2006 *Med. Phys* **33(5)** 1476-89
[2] Rich T and Dally E 1985 *Proceedings of the Second Mevatron User's Conference* 8103-15
[3] Doroshenko A V, Slonimskaya E M, Startseva Zh A, Lisin V A, Garbukov Ye Yu, Tarabanovskaya N A, Kokorina Yu L and Litviakov N V 2017 *Siberian Journal of Oncology* **16(6)** 11-7
[4] France A K 2013 *Make: 3D Printing: The Essential Guide to 3D Printers* (Maker Media, Inc.) p 222
[5] Miloichikova I A, Gavrikov B M, Krasnykh A A, Cherepennikov Y M, Shevchenko M V and Stuchebrov S G 2018 *Particles and Nuclei Letters* **15(7)** 963-6.
[6] Information on https://www.filaments.directory/en/plastics/sbs
[7] Information on https://www.3dquality.ru/catalog/product/prism_mini_v2_v_sbore/
[8] Sipilä P, Ojala J, Kaijaluoto S, Jokelainen I and Kosunen A 2016 *J. Appl. Clin. Med. Phys*. **17(1)** 360-73
[9] Information on https://www.iba-dosimetry.com/fileadmin/user_upload/rt-br-e-phantoms-for-ad_rev2_0813.pdf
[10] Information on http://www.teambest.com/CNMC_docs/radPhysics/electrometers/CNMC_T10010.pdf
[11] Information on http://www.teambest.com/CNMC_docs/radPhysics/parallel/CNMC_N23343.pdf
[12] Information on http://www.epson.ru/catalog/scanners/epson-perfection-v750-pro/
[13] Novikov V A, Gribova O V, Vasiljev R V, Choynzonov E L, Shtin V I, Shiianova A A, Surkova P V, Starceva Zh A and Shilova O G 2017 *AIP Conf. Proc.* **1882(1)** 020054.