Simulation of the X-Ray Beam Absorption by the ABS-Plastic Filled with Different Metallic Additives

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Abstract. This article is a part of the work on developing new materials for manufacturing filaments for fused deposition modeling (FDM). The computations of depth dose distributions for gamma-radiation in ABS plastic filled with lead and zinc additives of various concentration were performed via Monte Carlo technique and are represented in graphic form.

1. Introduction

Methods based on the use of gamma-active isotopes are an integral part of modern medicine [1-4]. There are always problems associated with planning procedures of radiation treatment of a patient when working with ionizing radiation. They control the required dose on the area of interest and minimize the dose load to critical organs. Dosimetric planning of treatment is mainly realized with methods based on computer simulations of the process [5]. However, these methods do not accurately take into account the characteristics of the emitter, which may depend on many factors. Availability of technology, allowing one to create phantoms for simulation of the interaction of gamma radiation with different parts of the patient's body, would develop experimental methods for planning such medical procedures. Not only does such technology require a method of manufacturing a tissue-equivalent material but also a method for quick creation of the items from them. Modern rapid prototyping technology fulfills all these requirements [6]. The solution would be to obtain filaments designed to work with 3D-printers based on the technology of fusing layering (Fused Filament Fabrication, FFF). The main parameters for the design are specified density and, accordingly, a certain nature of the interaction with gamma radiation.

It is necessary to theoretically estimate the interaction of modified ABS-plastic with gamma radiation based on the radiation source cobalt-60 to conduct research in this area.

2. Materials and methods

2.1. Test materials

ABS-plastic doped with various additive concentrations of zinc or lead was used as test materials in this study. The density of the modified materials was calculated using the formula:

$$\rho = \frac{\rho_{ABS} \cdot \rho_{add}}{k \cdot \rho_{ABS} + (100 - k) \cdot \rho_{add}}, \quad (1)$$

where ρ_{ABS} – density of ABS plastic; ρ_{add} - density of the material that is used as an additive; k - mass concentration of additive in the test material.

Figure 1 shows the dependence of the investigated material density on corresponding mass concentration of zinc and lead.

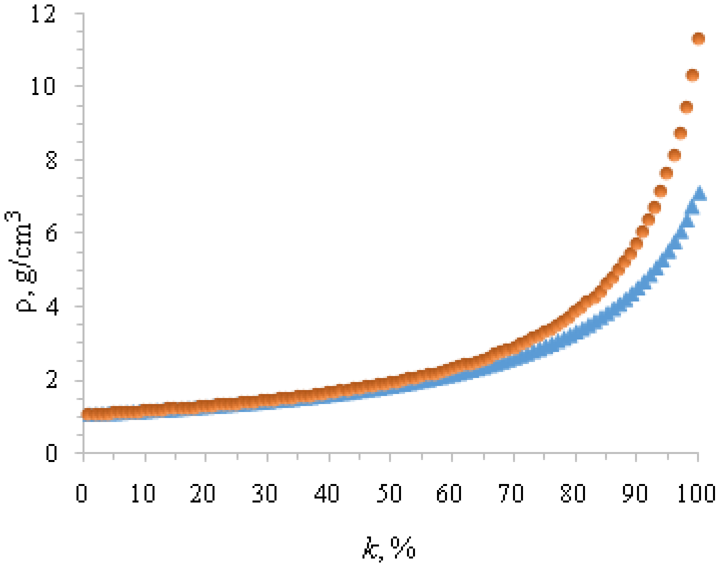

Figure 1. The dependence of the investigated material density on corresponding mass concentration of ● – zinc and ▲ – lead.

Specific materials densities which corresponds to the density of certain tissues and organs of the human body (1.06, 1.1, 1.5, 2.0, 2.5 g/cm^3) were chosen for calculations [7].

2.2. Software

"Computer laboratory (PCLab)" version 9.6 was used to simulate the interaction of gamma radiation with a modified ABS plastic in the mode "Phantom". This mode gives three-dimensional spatial distribution of the absorbed energy in the detector by calculation using Monte Carlo method [8].

2.3. The radiation source and the scheme of the experiment

Beam therapy system "Theratron 780" was selected as the source of gamma radiation. This system is based on the radionuclide cobalt-60. The software "Computer Laboratory (PCLab)" has a package for simulation of the source. The following parameters were used for the simulation: the spatial source of cobalt-60 of cylindrical shape with diameter 15 mm and height 20 mm. The source was placed in the steel box: the thickness of the side wall was 3 mm, of the upper end was 10 mm, and of the lower end was 1 mm. The box with the source was in the lead shield. Radiation from the source was emitted through a tungsten collimator. Figure 2 shows a scheme of the source with a constant collimator of therapy device Theratron 780.

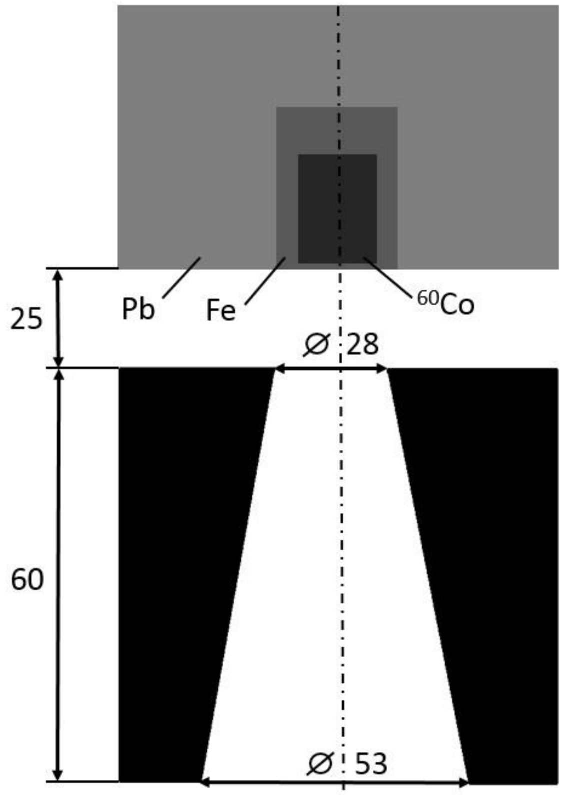

Figure 2. Scheme the source with a constant collimator of therapy device Theratron 780.

The emission spectrum of the source has 5 lines of gamma radiation of cobalt-60: 0.3469, 0.8263, 1.3324, 1.1732, 2.1588 MeV, and the line of electrons of internal conversion: 1.16488, 1.32414 MeV [8].

3. Results and analysis of the experimental results

Depth dose distributions of photon beam radiation in ABS plastic with additives of zinc or lead were obtained in this study. Figure 3 shows the calculated distribution of photons in a transverse plane of the test materials with densities of 1.1 and 2.5 g/cm3 at a depth of 2 mm. The calculated parameters were normalized by the maximum value in the detector.

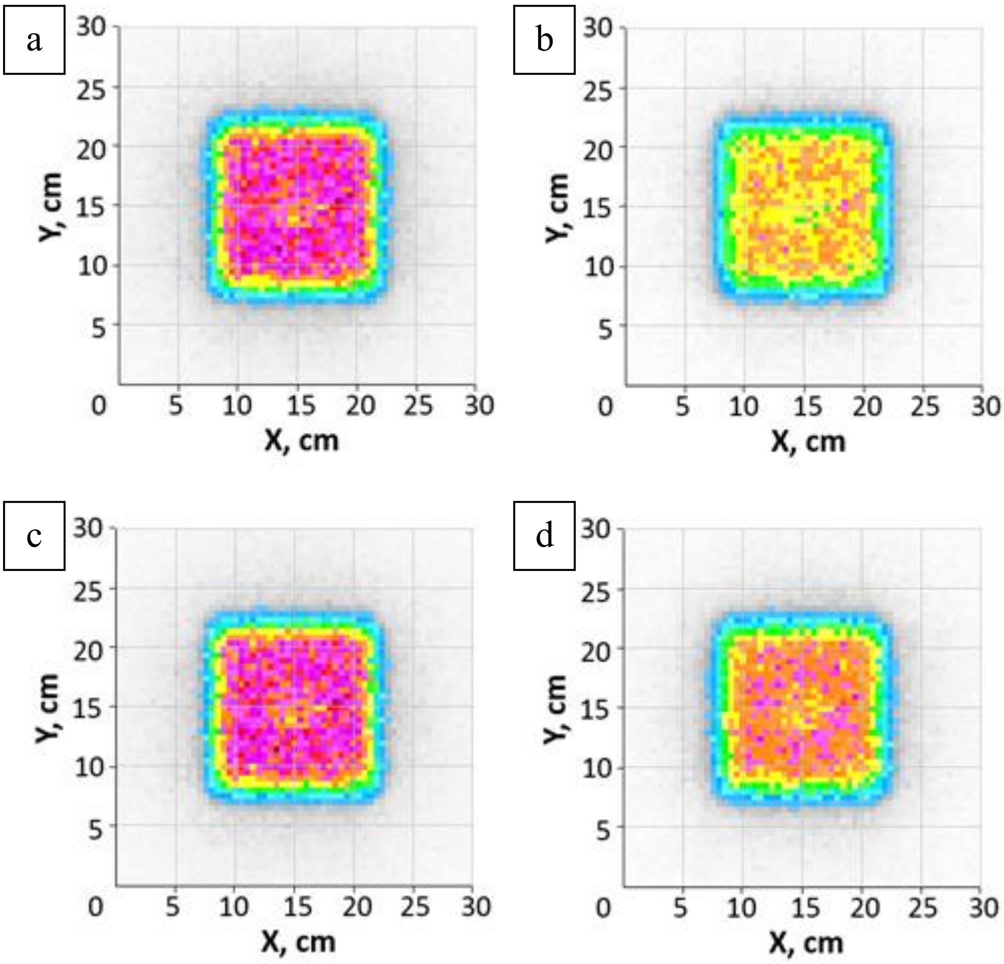

Figure 3. Photons distribution in the transverse plane:
a – ABS plastic with lead additive, density 1.1 g/cm^3;
b – ABS plastic with zinc additive, density 1.1 g/cm^3;
c – ABS plastic with lead additive, density 2.5 g/cm^3;
d – ABS plastic zinc additive, density 2.5 g/cm^3.

Figure 3 shows that the effect of various additives on the interaction of photon radiation with modified plastic increased with the increase of materials density. Dose distributions for zinc and lead additives were similar at low concentrations of additives. However, the dose distributions were significantly different for the cases of a large amount of additives.

Then depth dose distributions for the test materials with zinc and lead additives were calculated. Figure 4 shows the resulting dependences.

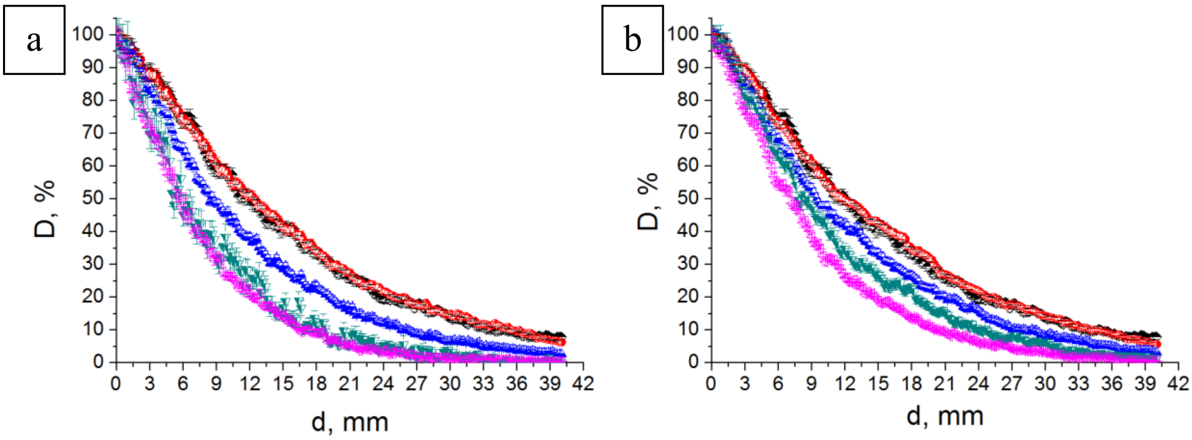

Figure 4. The absorbed dose depth distributions in test materials a – lead and b – zinc of different densities: –1.06 g/cm^3, –1.1 g/cm^3; – 1.5 g/cm^3; –2.0 g/cm^3; – 2.5 g/cm^3.

Figure 5 shows the difference between the interaction of photons with the test materials of the same density, but with different metal additives.

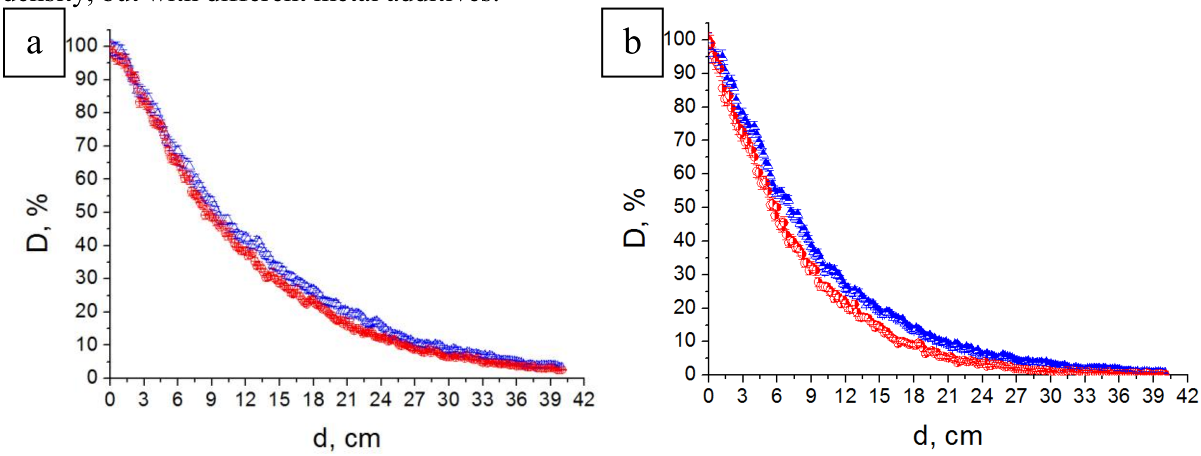

Figure 5. The absorbed dose depth distribution for ABS plastic with – lead and – zinc additives: a – density 1.5 g/cm3, b – density 2.5 g/cm3.

4. Summary

Absorbed dose depth distribution for the interaction of gamma radiation with the test materials of ABS plastic having different metal additives with different concentrations were calculated during the investigation. The calculations have shown the differences in the nature of the radiation interaction with the test materials of the same density, but with the different additives. This is especially true in the case of high densities. This occurs because of the complex combination of different factors that influence on the gamma rays interaction with the materials. On the one hand, the metal with a lower density has higher concentrations. However, this metal has a smaller total cross section of interaction with gamma radiation. It means that it is necessary to focus not on the mass density, but on the Hounsfield scale when selecting materials for the creation of phantoms simulating the gamma radiation interaction with different parts of the patient's body.

Since Hounsfield scale should be mainly determined experimentally, the next stage of this work will be: the 3D printing of modified ABS plastic with various additives of lead and zinc; the measurement of the actual density of the samples; obtaining experimental dependences of the Hounsfield scale on the concentration of metallic additives.

Acknowledgements
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