

Dosimetric characterization of 3D printed for ^{137}Cs gamma rays

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Abstract. The aim this paper is characterize materials for 3D printed with different infill percentages for ^{137}Cs gamma rays. The RAISE 3D PRO2 printer was used to print PLA and ABS plates. Using a ^{137}Cs source, the attenuation coefficient was obtained by the transmission method and results compared with PMMA. The readings were performed by a Radcal ionization chamber, model 10X6-6. The results of attenuation coefficients show that the PLA filament demonstrated a equivalent behavior to PMMA. The PLA plates exhibits an increase in radiation transmission when reduces the infilling, and ABS printing achieved same results for all infills.

Keywords. 3D printing; PLA; ABS

1. Introduction

The phantoms used to represent human tissue are constructed from equivalent tissue materials. In recent years, the use of filament commonly found commercially to phantom 3D printing technology for medical applications is evolving as new materials are being studied^[1]. This improvement is enabling the development of low cost phantoms that can be used at different energy ranges^[2].

The interaction of radiation with the material varies according to mass density, atomic number, and type of incident radiation, such as photons and charged particles. Absorption or attenuation mechanisms within the material may give different results at different energies, particularly in the diagnostic and therapeutic range.

This is due to different events, such as photoelectric effect, Compton scattering, and pair production, which could occur during interaction with matter.

The linear attenuation coefficient (μ) is considered to be the most useful variable to describe the real fraction of interacting photons, per unit of thickness, along their trajectory within a material^[3].

In order to compare materials for phantom printing in 3D technology, the aim of this paper is to analyze the attenuation coefficient obtained experimentally by the transmission method of the PLA and ABS printed prototypes with different thickness and infill percentages for ^{137}Cs gamma rays. As well, to consider substituting PMMA manipulation with the development of phantoms printed on this technology, more easily and at low cost.



2. Methods

2.1. Printing materials

The prototype materials (plates) analyzed in this paper were printed with PLA (Polylactic Acid) and ABS (Acrylonitrile Butadiene Styrene) filaments using the RAISE 3D PRO2 model 3D technology printer located in IPEN, shown in Figure 1.

Print performance is related to a three-dimensional Cartesian plane. The nozzle of the equipment moves along the X and Y axes during construction of the prototype layers. After each layer is finished, the platform (heated bed) is lowered on the Z axis, starting construction of a new layer and so on until the piece is finished.

The plates analyzed were printed with dimensions of 80 x 80 x 1 mm³ using +45°/-45° orientation layer thickness (z) of 0.2 mm and 100%, 95%, 85% and 50% infill variations for both filaments, using the Fusion Deposition Modeling (FDM) technique. Printing set-up were controlled using the ideaMAKER slicing software, according to Table 1. For comparison, 100 x 100 x 1 mm³ solid PMMA plates were used as material of reference.



Figure 1. RAISE 3D PRO2 printer general view from IPEN.

Table 1. Manufacture characteristics for PLA and ABS.

Material	Colour	Nominal Density (g/cm ³)	Nozzle Temperature (°C)	Heated Bed Temperature (°C)	Layer thickness (mm)	Print Speed (mm/s)
PLA	Transparent	1.24	210 - 220	60	0.2	50
ABS	Pure/White	1.05	240 - 250	105	0.2	50

2.2. Irradiations

Gamma irradiations of the plates were performed by a Cesa-Gammatron irradiator, Figure 2, consisting of a single Cesium-137 gamma source (γ) installed inside it, located in Instrument Calibration Laboratory - LCI in Nuclear and Energy Research Institute - IPEN.

The readings were performed by a Radcal ionization chamber, model 10X6-6¹, serial number 15533, coupled to a Radcal electrometer, model 9060, serial number 99-0390, positioned according to Figure 2.

The attenuation coefficient (μ) was obtained experimentally by the transmission method for the plates with 100% infill varying their thickness until 150 mm, as well as for the plates with the different infill percentages already mentioned.

When traversing a material, the greater the thickness of the material, the greater the number of interactions that occur, consequently less will be the final beam intensity.

All the plates were positioned in front of the beam exit and the values obtained in this procedure were analyzed using Oring® software. For each thickness and different infill, was determined the linear attenuation coefficient for all print material, according to Equation 1^[4;5].

$$I = I_0 e^{-\mu x} \quad (1)$$

I_0 is the initial beam intensity, and I is a beam intensity for a thickness x of the plates positioned between a source and the detector.

The coefficient of linear attenuation is related to the incident data energy, material number and density of the absorbing material. Thus, the linear attenuation coefficient is limited by the fact that it varies with the density of the absorber, even though the absorber material is the same and derived when beams used are monoenergetic^[4;5].

The results for both attenuation coefficients were compared with the results of the PMMA (Polymethyl methacrylate) plates as reference.

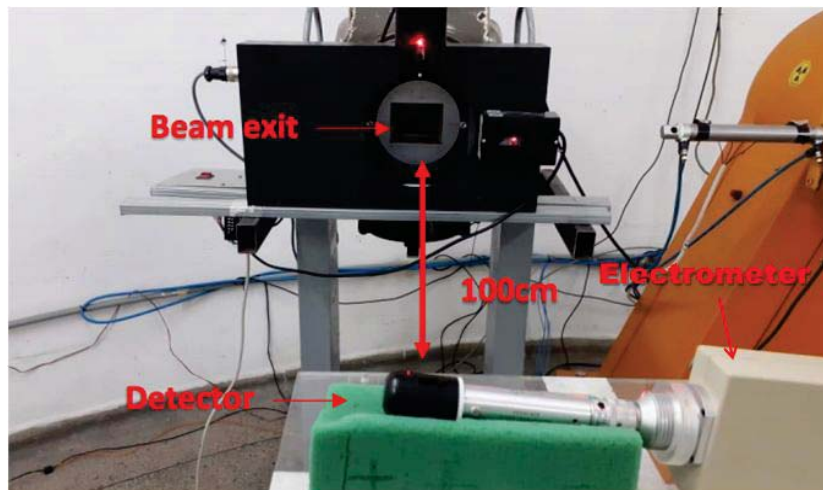


Figure 2. Measuring arrangement used in Cesa-Gammatron irradiator LCI-IPEN.

3. Results

3.1. Printing performance and printed phantoms

¹ The instrument used for dosimetry (Radcal ionization chamber-10X6-6) was chosen due to parallel studies on energy dependence above the range of radiodiagnostic qualities.

Print reproducibility tests were performed by printing three identical samples for each print mode. The result obtained was better than 1.0% for mass and an average of 0.8% for dimensions.

The plates impressions were simulated for different infill (Figure 3) using the ideaMARKER software. Results were compared with PMMA plates used as reference material.

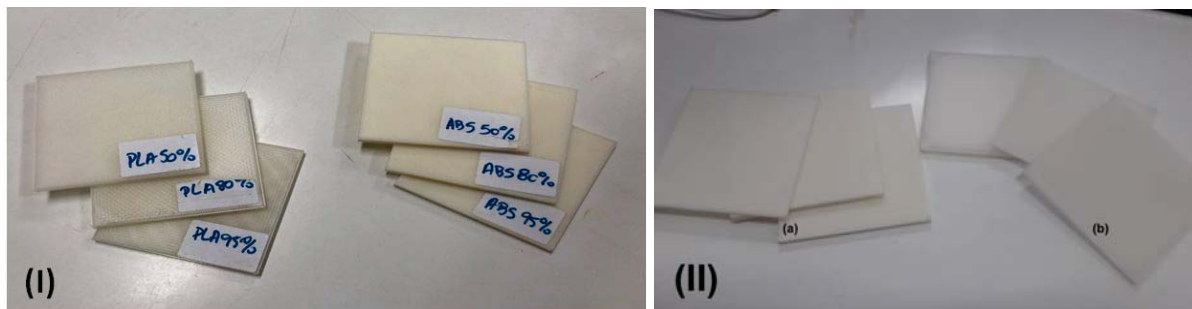


Figure 3. Phantoms plates used in the calculation of radiation transmission. **I.** PLA and ABS printed plates with 50%, 80% and 95% infill. **II.** (a) ABS phantom plates. (b) PLA phantom plate.

3.2. Radiation transmission results

Experimental results of experimental radiation transmission for 100% infill of ABS and PLA plates varying in thickness as well as for PMMA are shown in Figure 4. An exponential fit was made to the data points, obtaining an expected exponential behavior that can also be observed.

Comparing the obtained results, the Figure 5 demonstrate an agreement between an obtained coefficients. It is possible to observe differences in behavior of transmission of the plates in relation to PMMA value, in which the PLA has a similar attenuation to PMMA.

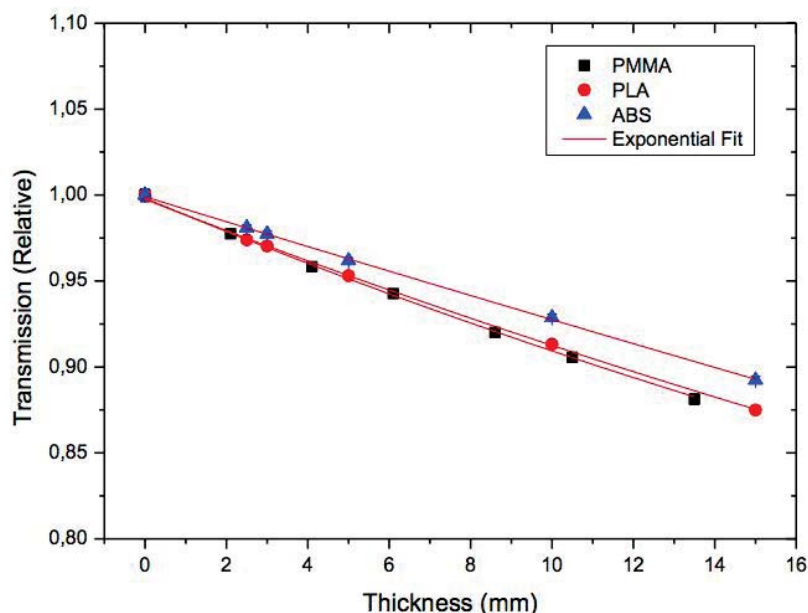


Figure 4. Comparison between the experimental transmission values of PLA, ABS and PMMA plates for different thicknesses.

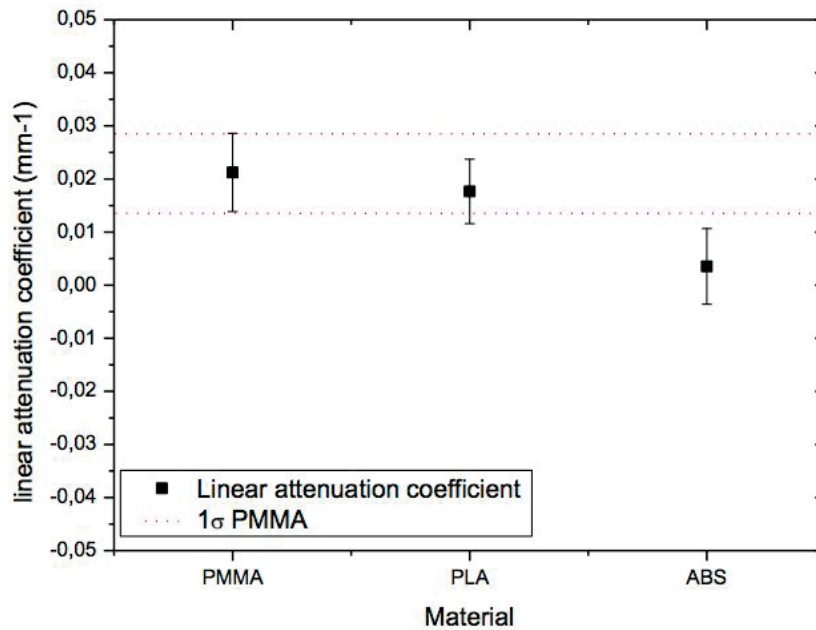


Figure 5. Agreement of linear attenuation coefficient values between PMMA, PLA and ABS

Figure 6 shows an experimental results of relative transmission for the 95%, 80% and 50% infilled of PLA and ABS plates. For these curves linear fit was performed, is also observed. For PLA plates, the intensity of the transmitted beam increases as the infill percentage decreases; and for ABS plates, the intensity of transmitted beam for infill percentage variations is constant.

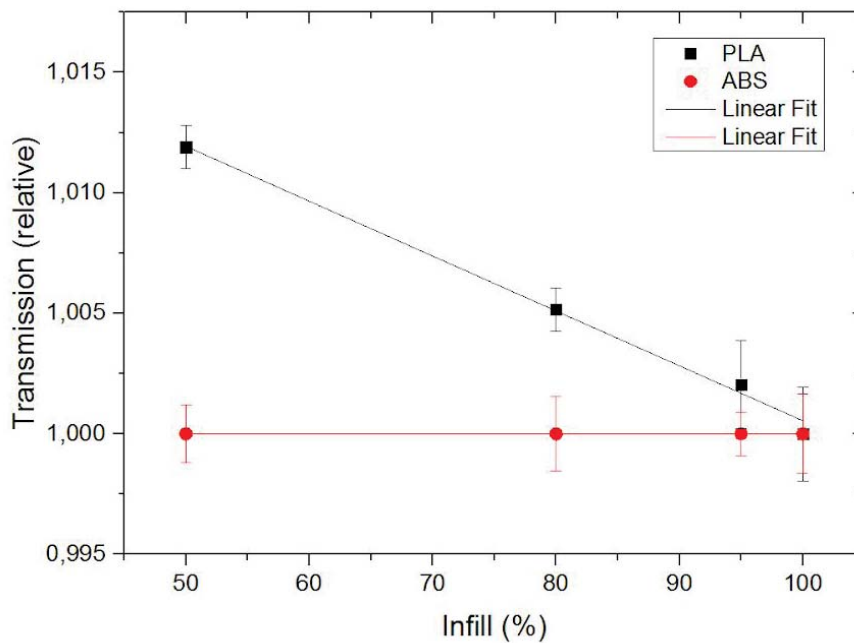


Figure 6. Relative transmission values for different infill percentages of PLA and ABS.

4. Discussion

Considering the experimental transmission results for ^{137}Cs gamma rays measured, the PMMA and PLA attenuations and linear attenuation coefficients presented statistically equivalent behavior within 1σ . Results obtained with ABS, one can observe a lower attenuation coefficients.

The evaluation of different infill percentages of a 3D printing material is related to the amount of material deposited during a printing, making it possible to change the density of the printed phantoms. This tool is an advantage of 3D printing technology and of great importance for a dosimetric characterization.

For infill percentage variations, the plates printed with PLA presented linear behavior of increase of the radiation transmission when the infilling is reduced, even equaling the experimental coefficient of ABS, for 100% infills.

The attenuation coefficients values for ABS filament remains the same for any percentage infill value in high energy gamma of ^{137}Cs . Advantageously, the phantom can be printed with a lower infill percentage and thus save on the amount of filament material and make faster prints.

5. Conclusion

The results show that the printing system used has good reproducibility and print quality. The different printing modes were characterized and presented relevant attenuation linear coefficient results for high Cesium-137 gamma rays.

Other paragraphs are indented (BodytextIndented style) For this energy range, the PLA filament demonstrated a similar behavior to PMMA. Already the filament of ABS, presented a linear coefficient of attenuation lower than them.

In relation to the percentage of plate infilling, the PLA presented experimental results of radiation transmission inversely proportional to the infilling percentage.

However, ABS filaments presented an advantage over its results. The phantom can be printed at a lower infill percentage (50%) that will have the same result as ^{137}Cs relative high energy radiation transmission. And so, to save on the amount of material used and optimize print time.

The different printing modes characterized together with their attenuation coefficients for the Ba-133 and Co-57 sources will be studied and used in the development of new 3D printed phantoms in our institute.

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