Reuse of 3D printed materials for dosimetry purposes

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Abstract. 3D printing technology has been a great ally of the medical industry due to it allows the obtaining of anatomical structures such as custom prostheses, implants and surgery planning simulators for the most several applications. There are in the market, several types of filaments used for 3D printing, being the most used thermoplastics Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA). Within the modeling and printing process, tests are made with different printing parameters and often part of the test material is discarded. The objective of this work was to study a methodology for recycling discarded materials printed in 3D printer for use in characterization studies for dosimetry purposes.

Keywords. 3D printing; Recycling; Dosimetry.

1. Introduction

There are several types of printers on the market that use different printing techniques. Fused Deposition Modeling (FDM) printers are more common and cheaper. FDM is a technique that uses a thermoplastic filament that is heated to its melting point and then extruded onto a platform to create the individual layers of a three-dimensional model created by specific software [1].

Of the hundreds of materials available for printing, the most widely used thermoplastics are acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) due to their low cost. The possibility of two-dimensional radiographic images to be converted into 3D print files, allows the construction of complex anatomical structures, which aroused the interest of the scientific community due to its numerous applications [2,3,4].

In the field of medical physics, this technology made it possible to obtain anthropomorphic phantoms for ionizing radiation dosimetry, requiring the characterization of materials available for 3D printing, as well as equivalence to human tissue. During the printing process, some parameters such as print speed and layer thickness influence sample characteristics and often some of the material used for testing is discarded. Considering the need for characterization of printed samples for use in phantoms, a methodology was developed using fused samples for reuse of discarded material in order to evaluate how heat treatment can influence the values of the linear attenuation coefficient of the materials and, consequently, if it is possible reuse the materials for dosimetry.

2. Materials and Methods

2.1. Material Recycling

An electric furnace operating at 0 to 250 degrees Celsius was used for the temperature and time analyzes required to fuse the structures of different compositions.

Structures composed of transparent PLA and black ABS were used for the experiment and different temperatures and time were applied according to the material used. Aluminum recipients (7 cm in diameter and 2.5 cm high) were used to accommodate discarded material (Fig 1).

Figure 1. Material (PLA) prepared for the application of the recycling tests.

2.2. Calculation of the linear attenuation coefficient μ

The Pantak / Seifert X-ray system, model Isovolt HS, located at the Instrument Calibration Laboratory of the Institute of Energy and Nuclear Research (LCI / IPEN), was used to obtain Kerma rate values.

Figure 2 shows the schematic assembled for the test. The samples were fixed to a collimator with a 2 cm x 2 cm aperture, at 60 cm from the focus, to ensure centering of the beam.

The applied current was 10 mA, for the series of implanted Radiation Qualities for CT applications (RQT), listed in table 1, where RQT 9 is the reference quality.

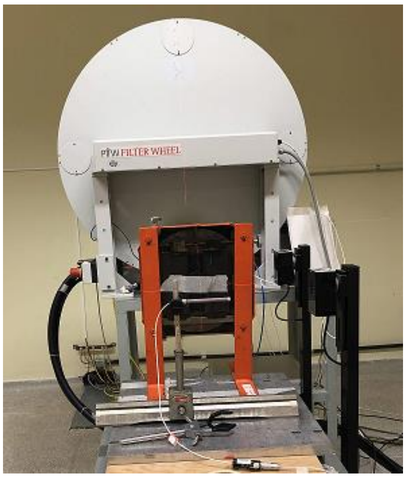

Figure 2. Schematic assembled for obtain Kerma rate values.

Table 1. Characterization of radiation quality series RQT.

Radiation quality	X ray tube voltage (kV)	Added filtration (mm Cu)	Nominal first HVL (mm Al)
RQT 8	100	0.20	6.9
RQT 9	120	0.25	8.4
RQT 10	150	0.30	10.1

The analysis of the behavior of recycled materials in relation to the interaction of radiation was made by calculating the linear attenuation coefficient using equation (1) [5].

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

where:

I is the initial intensity of the radiation beam;
I_0 is the intensity of the beam after crossing a material of thickness x;
μ is the linear attenuation coefficient of the material;

Two samples were printed with geometry and thickness (7 cm in diameter and 9 mm of thickness) of the recycled samples, for analysis and comparison (Fig.3).

Figure 3. Samples printed in transparent PLA and black ABS for comparison with recycled samples

2.3. *Evaluation in clinical applications*

For evaluation in clinical beams, images of the samples were taken in a computed tomography equipment with the calibrated Hounsfield units (HU), (Fig.4) to obtain gray scale values.

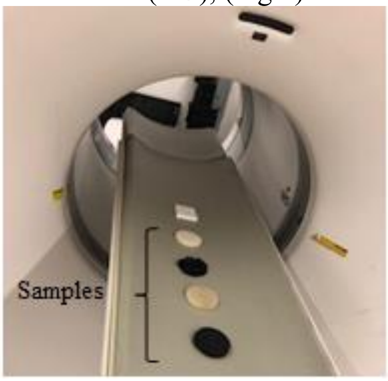

Figure 4. Positioning samples for exposure on a CT scanner

The skull protocol was chosen, where the exposure parameters can be seen in table 3. A region of interest (ROI) of each sample was analyzed, and the variations in HU values were compared.

Table 2. Exposure parameter used on CT scanner

Slice number	Thickness	Pit (mAs)	kV
1	10,6 mm	50	120

3. Results

The value of average temperatures and time obtained for the recycling of materials can be seen in table 3.

Table 3. Average temperatures and time obtained for recycled materials

Material	Temperature (ºC)	Time (min)
PLA	180	80
ABS	200	120

The results showed better performance for transparent PLA in relation to homogeneity. For ABS, as it is derived from petroleum, possible complications were expected in the applied recycling methodology, but the results obtained were satisfactory.

After the readings with the ionization chamber, correction factors were applied, in order to obtain the Kerma values to evaluate the materials.

Table 4 shows the results obtained for the Kerma values with uncertain for each material in the RQT radiation qualities of the LCI-IPEN equipment and the linear attenuation coefficient μ found.

Table 4. Kerma rates values obtained for each material in the RQT radiation qualities of the LCI-IPEN.

Material	Kerma Rates (mGy/min)			μ (mm^{-1})
	100 kV	**120 kV**	**150 kV**	
Kerma rates without attenuation	0.178 ± 0.001	0.271 ± 0.001	0.451 ± 0.003	--
Printed PLA	0.144 ± 0.001	0.221 ± 0.001	0.373 ± 0.001	0,022
Recycled PLA	0.143 ± 0.001	0.220 ± 0.001	0.371 ± 0.001	0,023
Printed ABS	0.151 ± 0.003	0.232 ± 0.002	0.388 ± 0.001	0,017
Recycled ABS	0.149 ± 0.001	0.228 ± 0.002	0.383 ± 0.002	0,018

The results for the measured values in Hounsfield units for each sample can be seen in Table 5. It was possible to compare the values of the printed samples with those of the recycled samples and to analyze the variations.

Table 5. measured values in Hounsfield units for each sample

Material	min HU	max HU	Average HU	STD
Printed PLA	27	81	53.3	8.4
Recycled PLA	123	163	145.7	5.5
Printed ABS	-199	-146	-173.7	7.8
Recycled ABS	-109	-45	-59	7.9

4. Conclusions

Variations found for printed and recycled samples may be related to material density after recycling. Different printing parameters may be applied during prototype acquisition, which influence the amount of material deposited on each printed layer and, depending on the type of printer used and the print setting, these layers may have air holes between them. Although high quality printing parameters were chosen in this paper, the results for the samples point to a difference between the densities of recycled and printed PLA/ABS samples. For more inclusive analysis, studies can be performed with samples from different printers to define the best print resolution to compare with samples of fused materials.

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5. References

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