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ANALYSIS OF ASA AND *WOOD CHARACTERISTICS* WITH VARIATIONS IN THICKNESS AND *INFILL DENSITY* AS 3D *PRINTING PHANTOM* RADIOLOGY MATERIAL

Suharyana, Mohtar Yunianto*, Ivara Salsabila Putri Aldicia
Physics Department, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret, Surakarta, Indonesia
*mohtaryunianto@staff.uns.ac.id

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ABSTRACT

This research was conducted to identify *wood filaments* and ASA as potential organ phantoms based on material density, CT number, electron density, effective atomic number, and radiation dose parameters. The thickness and density of the samples were varied to determine the effect on each parameter. The sample image was obtained from a CT *Scan* radiology test with the same exposure factor. The potential of samples as organ *phantoms* varies for each parameter. In *wood* filament samples, a thickness of 1 cm to 2 cm with a density of 20% can potentially be a lung organ *phantom* . Meanwhile, at a thickness of 5 cm with a density of 100%, it can potentially act as *a phantom* for bone, liver and muscle organs. In ASA filament samples with a thickness of 1 cm to 5 cm with a low density of 20%, it has the potential to be a lung organ *phantom and at a density of 100% it has the potential to be an* adipose tissue *phantom* .

Keywords: radiodiagnostics; *phantoms; Acrylic Styrene Acrylonitrile* (ASA); *wood*

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INTRODUCTION

Cancer is caused by the uncontrolled growth of abnormal body cells and develops rapidly [1] . An increase in new cases of cancer occurs every year which is also accompanied by an increase in the risk of death. In most cases that occur, cancer cells can only be detected after the final stage [2].

Radiodiagnostics is a way to detect or diagnose the presence of cancer cells in the body by using X-ray radiation. One of the radiodiagnostic tools available in Indonesia is the Computed Tomography Scanner (CT scan). CT scan uses X-rays as a radiation source and through computer processing it will produce two-dimensional images of organs. The image is formed from the X-ray process produced by the tube and then weakens when it penetrates the patient's body and is received by the X-ray detector [3].

To conduct research on image quality and the amount of attenuation, a phantom is used as a simulation model of an organ. If carried out in the human body it will be very dangerous because of high radiation exposure. Phantoms are made to resemble the properties and characteristics of a network. 3D printers are a technology that has been widely developed in the 21st century. This technology is starting to enter the medical world, one of which is for making phantoms. Phantoms printed with a 3D printer are able to visualize complex body tissue so that they can provide clinically realistic imaging [4].

A phantom is a design printed with a printer into a voluminous 3-dimensional shape. The design or design of the object model is created using special software in stl format. Next, printer layout settings are carried out such as speed, temperature and layer density. Then the printing process will be carried out. The advantage of this phantom 3D printer is that its shape is relatively real, complete and intact, like organ tissue in the body because the printing process is carried out layer by layer [5]. In order for a phantom to have the same similarities and characteristics as a body organ, the material from which it is made must be taken into account so that the characteristics of the phantom match the characteristics of the organ.

Nowadays, research on radiological phantoms is increasingly being developed. This is because phantoms have become research objects to replace the human body in the field of radiology. One of them is research conducted by Savi et al.,[6] regarding testing ABS, PLA, PETG, *wood,* TPU, HIPS filaments for use in phantom 3D printers on CT scan aircraft. In this research, samples were printed in the form of cubes with a thickness of 2 cm and variations in infill density of 60%, 80%, 100%. The results of this study show that wood filaments with an infill density of 80% are similar to body fat and an infill density of 100% is similar to the liver.

The research conducted by Ma et al., [7] is regarding the classification of X-ray attenuation and Hounsfield Unit Value on phantoms using CT Scan illumination. Samples are made with ASA, HIPS, ABS and PP materials. The phantom sample was printed as a cylinder with an infill density of 100%. The results of this study show that the ASA material exactly resembles water with a HU value of +2 HU.

This research identifies different wood and ASA 3D printer materials as potential for making phantom materials with body organs that will be analyzed later. This research was also carried out by varying the thickness of the material and infill density. The research that will be carried out is identifying different wood and ASA 3D printer materials as potential for making phantom materials with body organs that will be analyzed later. This research was also carried out by varying the thickness of the material and infill density.

Sample characterization was carried out through radiological tests with CT scans, CT number calculations, absorbed dose calculations, material density calculations, relative electron density value calculations, electron density per mass, and electron density per volume, as well as effective atomic number calculations. The results of the data obtained are compared with the values of the organ parameters according to the reference used. Sample characterization was carried out through radiological tests with CT scans, CT number calculations, absorbed dose calculations, material density calculations, relative electron density value calculations, electron density per mass, and electron density per volume, as well as effective atomic number calculations. The results of the data obtained are compared with the values of the organ parameters according to the reference used.

METHOD

Making Test Samples

The samples were designed with Autodesk Fusion 360 software into a block shape . Foreign M - each sample is made from 2 different filaments with 5 thickness variations and 5 infill density variations. For each filament, the dimensions used are 3 cm long, 3 cm wide, and variations in thickness, namely 1 cm, 2 cm, 3 cm, 4 cm and 5 cm. ASA filament samples were printed using the GOLDWIN 3D *printer and wood* filament samples were printed using the ANET AET4 3D *printer.* For each thickness variation, the sample is printed with 5 density variations, namely 20%, 40%, 60%, 80%, and 100%. So, there are a total of 50 test samples.

Material Density Test

The material density test is determined by measuring the mass and volume of the sample. Mass is measured by weighing the sample using a digital balance. Meanwhile, the sample volume was measured by measuring the increase in distilled water volume. Measurements using fluid in the form of distilled water were carried out so that the results were more accurate because the samples used in this research had a hollow structure. This test is carried out to obtain a density value which shows the density of a substance which is expressed by the mass per unit volume and can be determined using equation 1

$$\rho = \frac{m}{V} \qquad (1)$$

CT *Scan Radiology Test*

The CT Scan radiology test aims to obtain digital images of each sample. From this image, the CT number value will be obtained using the ROI technique, electron density, and radiation dose for each sample material tested. One of the properties of X-rays is that they can penetrate materials and are attenuated by the materials they pass through. The interaction between X-rays and a material will cause the X-rays to lose some of their intensity. The attenuation or weakening of X-ray energy depends on the atomic number of the material, the density and thickness of the material. So, the radiation intensity after passing through the material is smaller than the initial intensity. The intensity value after passing through the material can be calculated using equation 2 which shows the gray level in the image [8].

$$I = I_0\, e^{-\mu x} \qquad (2)$$

Body organs that have gone through the scanning stage on a CT scan are then analyzed until the CT Number is obtained. According to Guswantoro et al [9], relative electron density can be obtained from the CT *Number value* as in equations 3 and 4 below.

$N_e = 1{,}052 + 0{,}00048N_{CT}$, for CT Number values > 100 (3)

$N_e = 1{,}000 + 0{,}001N_{CT}$, for CT Number value < 100 (4)

The effective dose received in the sample can be obtained through calculations using exposure factors and conversion values. The effective dose to the sample after irradiation can be calculated using equation 5 [10].

$$E = DLP \times k \qquad (5)$$

Analysis of the atoms that make up the filament

Analysis of the constituent atoms in each filament was also carried out to obtain electron density per mass, electron density per volume and effective atomic number. Electron density and the number of electrons will affect the interaction of photons with matter. Electron density per mass (EDG) can be obtained by multiplying Avogadro's number by the number of atoms, atomic mass, and fraction weight as in equation 6 [11].

$$\rho_{e(EDG)} = N_A \sum \frac{W_i Z_i}{A_i} \tag{6}$$

Electron density per volume is obtained by multiplying the electron density per mass (EDG) value with the sample density, as stated in equation 7

$$\rho_{e(EDV)} = \rho_{e(EDG)} \times \rho \tag{7}$$

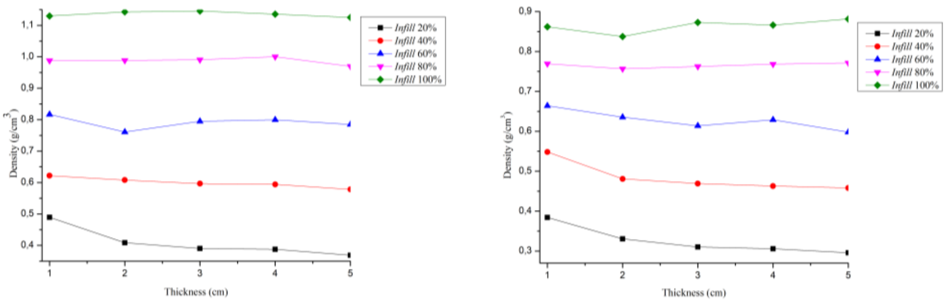
The effective atomic number is the average atomic number for a mixture, the value of which is a calculation of the atomic number, atomic mass and fraction weight, as in equation 8 below.

$$Z_{eff} = \frac{\sum \frac{w_i Z_i}{A_i}}{\sum \frac{w_i}{A_i}} \tag{8}$$

RESULTS AND DISCUSSION

Density or density

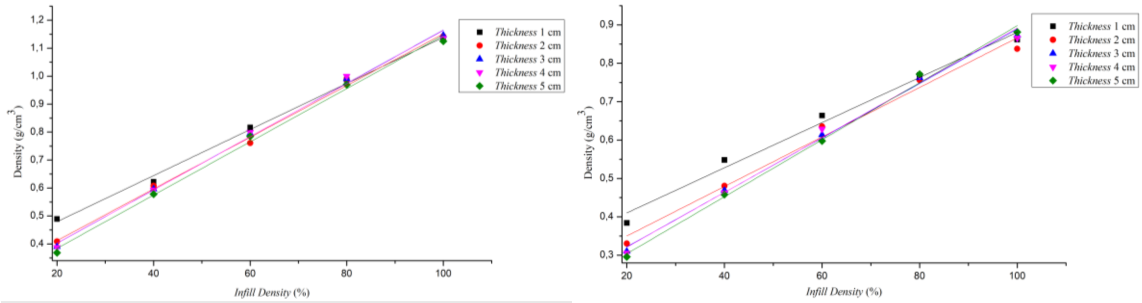
The phantom samples that have been printed are then tested for material density. From the material density test that has been carried out, mass and volume measurement data are obtained. The measurement data is then processed using equation 1 to obtain the density value for each sample . To find out the relationship between thickness and density values, you can see the combined graph in Figure 1 below



(a) (b)

Figure 1. Graph of the relationship between material thickness and density values for (a) wood (b) ASA filament samples

From the graph in Figure 1 , it can be seen that there is no trendline formed. The trendline shows that the data tends to increase and decrease continuously [12]. Meanwhile, in the graph in Figure 1 above, you can see that the data obtained goes up and down so that a trendline is not formed and there is no linear, exponential or polynomial regression. This shows that the independent and dependent variables have no relationship. The thickness of a sample does not affect the value of the sample density. Meanwhile, to find out the relationship between infill density and density, it can be seen in Figure 2 below.



(a) (b)

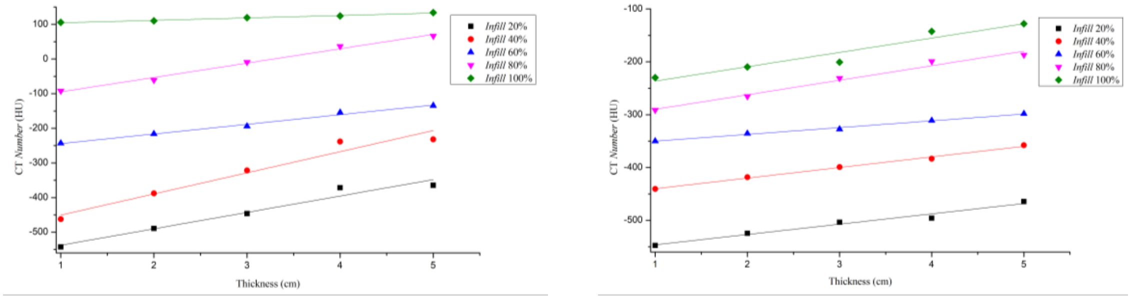
Figure 2. Graph of the relationship between *infill density* and density values in (a) wood (b) ASA filament samples

The statistical method used is the Pearson correlation coefficient. Pearson correlation is a correlation to determine the relationship between two variables [13]. The correlation coefficient (R) shows whether or not the relationship between the independent and dependent variables is strong. The correlation coefficient value is between -1 to 1 ($-1 \leq r \leq 1$). The independent and dependent variables have a strong correlation if the R value is greater than 0.5 or smaller than -0.5 [14] . From graph 2 it shows that the R value or average correlation coefficient is 0.9. Graph 2 shows a linear graph that rises continuously. The R value obtained is close to 1, so it shows that the denser the sample structure, the greater the density value obtained. The relationship between density and density value is directly proportional because density only affects the value of the mass measurement, not the volume.

CT *Number*

The printed Wood and ASA filament phantom samples were then tested with an X-ray aircraft. Radiological tests were carried out using X-rays using a Siemens Healthineers SOMATOM go CT Scan. Top series 120756 with digital image results in DICOM files . The digital image resulting from the CT scan can be used to determine the CT Number value. In this research, the CT Number value was determined by forming a gray level intensity measurement area or Region of Interest (ROI) using the RadiAnt DICOM Viewer software. The ROI is elliptical and for each sample measurements were taken at 9 points in 1 slice. The slice chosen to perform ROI is the slice that has the clearest image. The ROI area in determining the CT Number is 0.006068 cm^2 which represents 2 px. The ROI formed on the image will display information on the ROI area, minimum, maximum values, average CT Number, and standard deviation.

From the CT Number value data for each sample, a relationship can then be obtained between variations in sample thickness and density and changes in the CT Number value. Samples with the same density at different thicknesses have relatively different values. To find out how the variation in sample thickness affects the CT Number value, you can see the combined graphic in Figure 3 below.

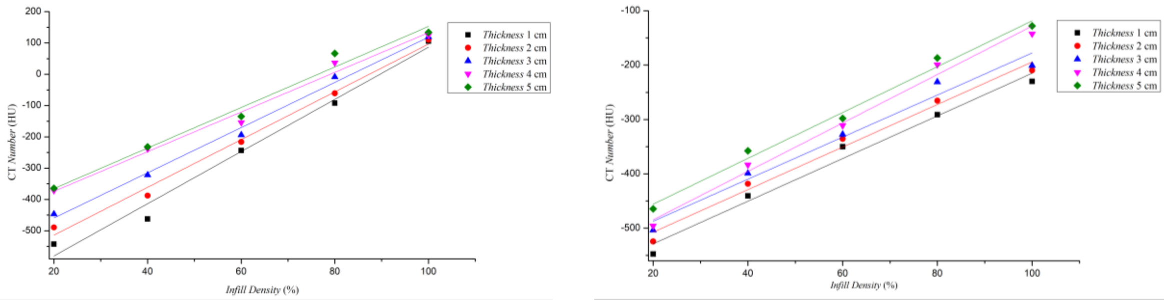


(b)

Figure 3. Graph of the relationship between material thickness and CT *number value* for (a) wood (b) ASA filament samples

The R value in the graph is 0.9. So the graph shows that the relationship between the independent variable thickness and the dependent variable CT Number is very strong. The thicker the sample, the greater the CT Number value . X-rays have the property of being able to penetrate any material they pass through. When X-rays pass through a material, the energy will be absorbed by the material. In equation 1 it can be seen that the intensity after passing through the material will be smaller compared to the initial intensity. When passing through the sample, the X-rays will experience attenuation because the sample has attenuation capabilities that can absorb X-ray energy. The intensity of X-rays decreases as they pass through thicker samples.

This research also uses density variations in the sample structure. So, you can find out how the infill density affects the CT Number value. Figure 4 below is a graph of the relationship between density and CT Number



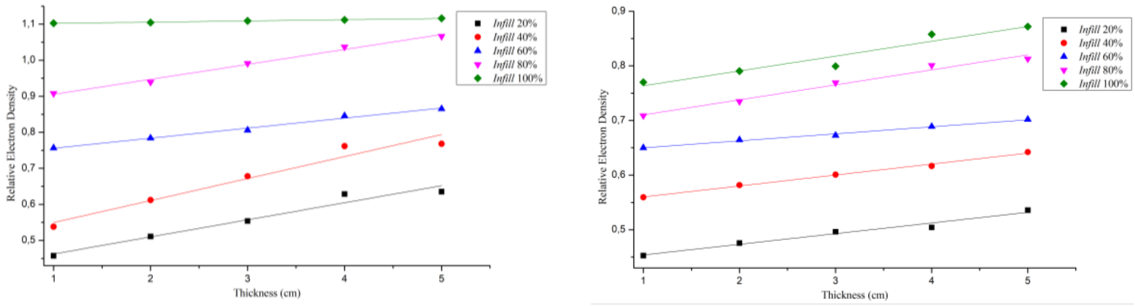
(b)

Figure 4. Graph of the relationship between material *infill density* and density values in filament samples (a) wood (b) ASA

The graph above forms a linear regression that increases continuously. The correlation coefficient or R in the combined graph in Figure 4 shows a value of 0.9. So, the independent variable has a strong relationship with the dependent variable. In a digital image, the brightest or white part indicates the most solid part or sample with the highest density. The grayer or blacker the density level is. The density level corresponds to the CT Number. Because the denser the sample, the greater the sample's ability to attenuate X-ray energy after passing through it, the greater the resulting CT Number value.

Relative Electron Density

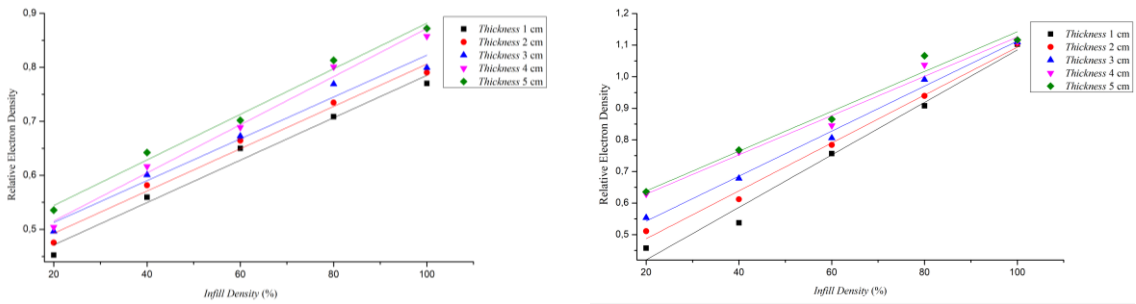
Relative electron density is a comparison of the electron density in a material with the electron density in a reference material, namely water. The relative electron density value in the sample is influenced by the CT *Number value.* By using the CT Number value that has been obtained, the relative electron density value can be calculated using equations 3 and 4.



(b)

Figure 5. Graph of the relationship between material thickness and relative electron density values in filament samples (a) wood (b) ASA

From the graph in Figure 5, you can see the relationship between thickness and relative electron density values. The graph shows a linear graph that increases continuously with an R value of 0.9. However, the gradient or increase in electron density values from thickness variations is not significant enough. This is because electron density is not influenced by the thickness or size of a sample.



(b)

Figure 6. Graph of the relationship between material *infill density* and relative electron density values in filament samples (a) wood (b) ASA

The graph in Figure 6 shows the relationship between *infill density* and the relative electron density value which forms a linear regression with an R value of 0.9. This figure is considered strong to show that there is a relationship between density as the independent variable and electron density as the dependent variable. The denser the structure of the sample, the greater the comparison value between the electron density in the sample and the electron density in water.

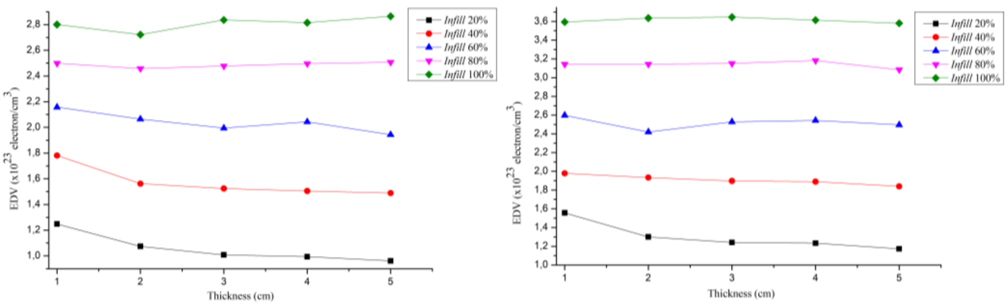
Electron Density per Mass (EDG)

Each filament has different constituent elements and has a different number of electrons in each element. This affects the number of electrons that will interact with X-rays during the radiation process. The total density of electrons that make up a material in one gram can be calculated by Electron Density per Gram (EDG). EDG can be obtained from calculating the composition of each constituent element via equation 6.

Acrylic Styrene Acrylonitrile (ASA) filament is composed of carbon, hydrogen, nitrogen and oxygen components with the chemical formula $C_{18}H_{23}NO_2$. Wood filament is a filament mixed with 30% cellulose and 70% Polylactic Acid (PLA). Cellulose and PLA are composed of carbon, hydrogen and oxygen components with the chemical formulas $C_6H_{10}O_5$ and $C_3H_4O_2$. From each constituent component, the fraction weight, atomic number, atomic mass, and multiplied by Avogadro's number are calculated. So, the EDG value obtained for the ASA material is 3.25×10^{23} electrons/gram. Meanwhile, the EDG value for wood material obtained in this study was 3.18×10^{23} electrons/gram.

Electron Density per Volume (EDV)

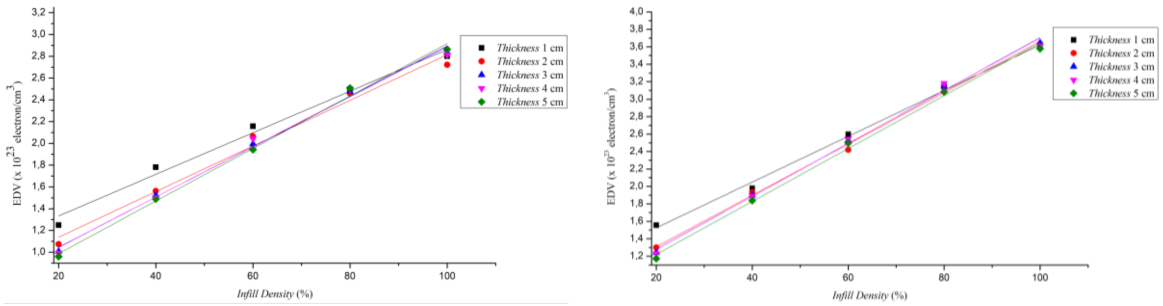
In determining the interaction between photons and organs in the sample volume size can be calculated using Electron Density per Volume (EDV). EDV can be obtained by multiplying the EDG value on the filament by the density of each sample as in equation 7. The EDV value for each sample is different because it is influenced by the density of the sample.



(b)

Figure 7. Graph of the relationship between material thickness and electron density values per volume in filament samples (a) wood (b) ASA

The graph in Figure 7 shows the relationship between variations in sample thickness and the EDV value results and it can be seen that the graph does not form a linear, exponential or polynomial regression. The electron density that makes up a sample is not influenced by the thickness or size of the sample. At both low and high thicknesses, the electron density value is constant.



(b)

Figure 8. Graph of the relationship between *infill density* and electron density value per volume in filament samples (a) wood (b) ASA

The graph in Figure 8 shows the relationship between the density of the structures that make up the sample and the EDV value. It can be seen in the graph that a continuous upward trendline is forming. The average correlation coefficient or R formed is 0.9. This proves that there is a strong correlation between the independent variable, namely density, and the dependent variable, namely EDV. The density of a sample is directly proportional to the resulting EDV value. The denser the sample structure, the greater the number of electrons in one unit volume, and vice versa. EDV is not affected by thickness, only sample density influences it.

Effective Atomic Number (Zeff)

The effective atomic number or Zeff is influenced by the atoms that make up a material or filament. Similar to EDG, Zeff can be calculated using fraction weight, atomic number and atomic mass as in equation v. Zeff is only influenced by differences in the components that make up a material, so the variations in density and thickness carried out in this research do not affect the Zeff value. The Zeff value at any density or thickness remains constant as long as it is made from the same material.

Acrylic Styrene Acrylonitrile (ASA) filament is composed of carbon, hydrogen, nitrogen and oxygen components with the chemical formula $C_{18}H_{23}NO_2$. Wood filament is a filament mixed with 30% cellulose and 70% Polylactic Acid (PLA). Cellulose and PLA are composed of carbon, hydrogen and oxygen components with the chemical formulas $C_6H_{10}O_5$ and $C_3H_4O_2$. From each component, the fraction weight, atomic number and atomic mass are then calculated. So the value of the effective atomic number of the ASA material is 3.50. Meanwhile, the value of the effective atomic number for Wood material is 4.18.

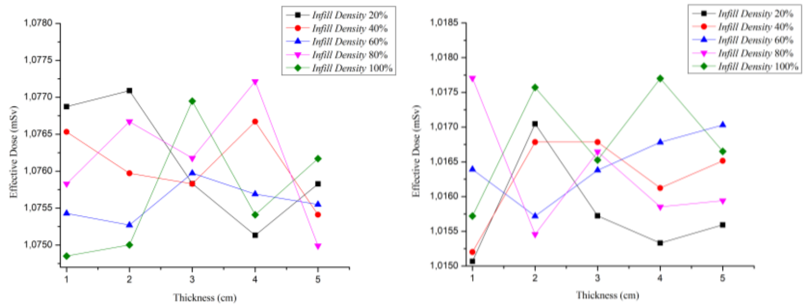
Effective Dosage

In this study, the effective dose was obtained using Indose CT software by inputting digital images. The radiation parameters on the CT *scan* are used to obtain the CT *Scan output dose values,* namely the CTDIvol and DLP values. *Computed Tomography Dose Index Volume* (CTDIvol) is the device's output dose which is influenced by exposure factors. CTDIvol values when irradiating *Wood* and ASA filament samples is 0.44 mGy, because the irradiation on both filaments uses the same exposure factor. Meanwhile, *Dose Length Product* (DLP) is the output dose of the device throughout the irradiation and is influenced by exposure factors. The DLP value under *Wood* filament irradiation is 14.23 mGy cm and under ASA filament irradiation it is 15.06 mGy cm. This is because the length of exposure to the two filament samples is different.

The sample area is calculated using AP and LAT to obtain the effective diameter value, as in the x equation. LAT is a horizontal line whose right and left ends are the boundaries of the sample to be calculated. Likewise, AP is a vertical line whose upper and lower ends are the sample boundaries. During the sample printing process, the size that has been set for the sample is 3 cm long and 3 cm wide. However, on IndoseCT it read ±3 cm. This is because when creating the AP and LAT lines the image displayed is less clear and broken, resulting in a lack of accuracy in data collection.

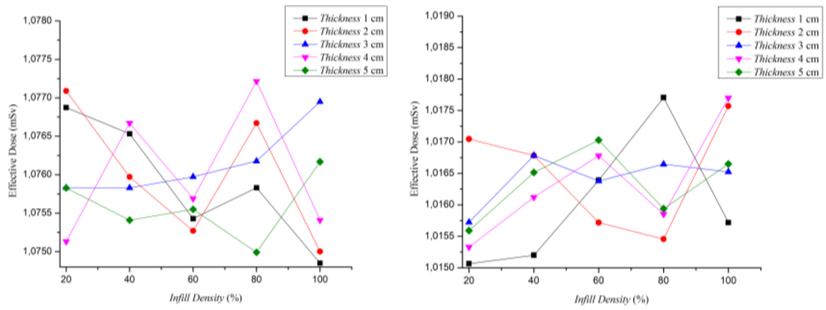
Size-Specific Dose Estimate (SSDE) is the dose in a sample which is influenced by the correction value based on sample size. SSDE is obtained based on equation 2.10. Apart from that, there is also an output in the form of an effective dose which is the dose absorbed in each tissue multiplied by the tissue weighting factor specified in the International Commission on Radiological Protection (ICRP). The effective dose value can be obtained from equation 2.11.

For *Wood* filaments, the SSDE and effective dose values obtained were 1.46 and 1.02 mSv. Meanwhile, for ASA filaments, the SSDE values and effective dose obtained were 1.46 and 1.08 mSv.



(b)

Figure 9. Graph of the relationship to the effective dose value for (a) wood (b) ASA filament samples



(b)

Figure 10. Graph of the relationship between *infill density* and effective dose value for (a) wood (b) ASA filament samples

Based on figures 9 and 10 above, it can be seen that the thickness or density of the sample structure does not affect the effective dose. The trendline formed on the graph does not increase or decrease continuously. So that no regression is formed, whether linear, polynomial or exponential. The SSDE value and effective dose are influenced by exposure factors and the area of the irradiation object.

Potential Radiological Phantoms

The value of each parameter that has been obtained is then compared with the reference. This aims to find out the potential of each sample as a radiological phantom to replace human organs. The database of organ characteristic values was obtained from The International Commission on Radiation Units and Measurements (ICRU) Report 44, Phantom Gammex 467, Phantom CIRS 062M, Phantom ISIS Cube, and references from other research journals. The potential phantom organ is selected with the smallest relative difference from the reference value and confirmed by at least one reference.

Table 1. Potential of *wood* filament samples as *phantoms* of human organs

Sample	Parameter					
	Density (g/cm ^{3})	CT *Number* (HU)	Electron Density	EDG (e^-/g)	EDV (e^-/cm ^{3})	Zeff
1cm 20%	Lungs	Lungs	Lungs	Solid bones	Lungs	Rib
1cm 40%	-	Lungs	-		-	
1cm 60%	-	-	-		-	
1cm 80%	Breast	Adipose tissue	Adipose tissue		Adipose tissue	
1cm 100%	Trabecular bone	Muscle and cartilage	Internal bones		Heart	
2cm 20%	Lungs	Lungs	Lungs		-	
2cm 40%	-	-	-		-	
2cm 60%	-	-	-		-	
2cm 80%	Breast	Adipose tissue	Adipose tissue		Adipose tissue	
2cm 100%	Trabecular bone	Muscle and cartilage	Internal bones		Trabecular bone	
3cm 20%	-	-	-		-	
3cm 40%	-	-	-		-	
3cm 60%	-	Adipose tissue	-		-	
3cm 80%	Breast	Muscles and soft tissue	Breast		Adipose tissue	
3cm 100%	Trabecular bone	Muscle and cartilage	Trabecular bone		Trabecular bone	
4cm 20%	-	-	-		-	
4cm 40%	-	-	-		-	
4cm 60%	-	Adipose tissue	-		-	
4cm 80%	Breast	Muscles and soft tissue	Brain		Adipose tissue	
4cm 100%	Trabecular bone	Muscle and cartilage	Trabecular bone		Trabecular bone	
5cm 20%	-	-	-		-	
5cm 40%	-	-	-		-	
5cm 60%	-	Adipose tissue	-		-	
5cm 80%	Breast	Liver and parenchymal organs	Heart		Adipose tissue	
5cm 100%	Trabecular bone	Muscle and cartilage	Trabecular bone and deep bone		Heart	

Table 2. Potential of ASA filament samples as *phantoms* of human organs

Sample	Parameter					
	Density (g/cm^3)	CT *Number* (HU)	Electron Density	EDG (e^-/g)	EDV (e^-/cm^3)	Zeff
1cm 20%	-	Lungs	Lungs	Lungs	-	Soft tissue
1cm 40%	Lungs	-	-		Lungs	
1cm 60%	-	-	-		-	
1cm 80%	-	-	-		-	
1cm 100%	Adipose tissue	-	-		-	
2cm 20%	-	Lungs	Lungs		-	
2cm 40%	Lungs	-	-		Lungs	
2cm 60%	-	-	-		-	
2cm 80%	-	-	-		-	
2cm 100%	-	-	-		-	
3cm 20%	Lungs	Lungs	Lungs		-	
3cm 40%	Lungs	-	-		Lungs	
3cm 60%	-	-	-		-	
3cm 80%	-	-	-		-	
3cm 100%	Adipose tissue	Adipose tissue	-		-	
4cm 20%	Lungs	Lungs	Lungs		-	
4cm 40%	Lungs	-	-		Lungs	
4cm 60%	-	-	-		-	
4cm 80%	-	Adipose tissue	-		-	
4cm 100%	Adipose tissue	-	-		-	
5cm 20%	Lungs	Lungs	-		-	
5cm 40%	Lungs	-	-		Lungs	
5cm 60%	-	-	-		-	
5cm 80%	-	Adipose tissue	-		-	
5cm 100%	Adipose tissue	-	-		-	

CONCLUSION

This research uses variations in thickness and infill density which influence the characteristics of the sample itself. The density value, relative electron density, and electron density value per volume are only influenced by the density of the structures that make up the sample, but are not influenced by the thickness or size of the sample. The CT *Number value* is influenced by variations in sample thickness and density. Meanwhile, the values of electron density per mass, effective atomic number, and effective dose are not influenced by the thickness or density of the sample. The samples in this study have different potential organ phantoms, depending on the parameters used. Wood filament samples with low density and thickness can act as lung phantoms, while those with high density and thickness can act as bone and liver phantoms. ASA filament samples with low density and thickness can serve as lung and adipose tissue phantoms.

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