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Fabrication and Characteristics of X-Ray Radiation Shield base on Polyester and Lead Acetate as Alternative of Replacement Radiation Shielding Lead Glass

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ABSTRACT

In this thesis, a study about the effect of polyester resin as matrix and lead acetate as filler on the manufacture of X-ray radiation shields and how the physical and mechanical properties and thermal properties are discussed. The type of material used to speed up the curing time is the mekpo catalyst. Lead acetate varied (2, 4, 6, 8, and 10) wt% with a thickness variation of 0.5cm, 0.75cm, 1.0cm, 1.25cm and 1.50cm. The results showed that the physical properties (density 1.9 gr / cm^3) on the composition of 10% wt lead acetate and 85% wt polyester resin with a thickness of 1.5 cm were the best results. The higher the composition of lead acetate, the higher the density value. The best radiation intensity results from X-ray radiation shield samples showed the composition of 10% wt Pb and 85% wt polyester resin (0.18μGy, 0.95μGy and 1.6μGy) with X-ray voltage conditions (40kV, 50kV and 60kV), the value of light transmission in this composition is 83% still in accordance with ISO standards on lead glass. The results of mechanical properties testing (press test 79 kg/cm^3 and hardness test 38) is the best value on the composition of 85: 10: 5% wt with 1.5cm thickness. This shows that the composition of 85: 10: 5% wt is the most homogeneous composition resulting in optimum mechanical properties. The results of the DSC test showed that the endothermic temperature was 85: 10: 5% wt with 1.5cm thick was the best with a temperature of 377^{0}C. From all radiation shield sample testing, composition 85: 10: 5% wt the best physical properties and mechanical properties in accordance with ISO standards and SNI-16-6656-2002 concerning lead glass.

Keywords : Polyester resin, lead acetate, X-Ray Voltage (kV), linear attenuation coefficient *(μ)* and radiation Intensity.

I. INTRODUCTION

The use of ionizing radiation such as X-rays in the field of medicine for the use of therapy and diagnostics is very common. However, a part from the benefits of its use, radiation that affects the human body can also cause harm to patients, workers and the general public from the lightest to the most fatal. Therefore a radiation shield is needed for the purpose of radiation protection [1][5].

The radiation protection program aims to protect radiation workers and the general public from the dangers of radiation caused by the use of radioactive substances or other ionizing radiation sources. To achieve a safe radiodiagnostic room condition for radiation workers, patients and the community, it is stipulated by the Nuclear Energy Supervisory Agency that it uses materials equivalent to 2 mm lead. In the implementation of radiation protection efforts must be carried out in accordance with the ALARA (As Low As Reasonably Achievable) principle in order to minimize exposure received by the radiation workers [1][7].

In this study using resin polyester as a base material for glass replacement, lead acetate powder as a filler and a catalyst to accelerate curing time and increase the crosslinking of the polymer.

This resin will later bind Pb (lead) so that the result becomes a transparent radiation shield. From the mixture it is expected to know the attenuation coefficient value of lead absorption on X-ray radiation.

II. METHODS AND MATERIAL

Radiation safety is a branch of science that studies human safety and health problems. One of the nuclear applications for health in the field of medicine, especially the radiology unit, is irradiation for the purpose of diagnosis by X-ray examination.

In the field of radiation protection, three basic strategies are applied which are known as the principle of radiation protection, that is: reduce time around radiation sources, position themselves as far as possible from radiation sources and use radiation shields [1].

Interaction Radiation of matter

In the interaction of photons with matter, photons can channel their energy into electrons in the material and there are three possibilities that occur [4], that is:

a) Can penetrate material without interacting.
b) Can interact with matter and all the energy of the photons absorbed in the material.
c) Can interact and scatter, then turn from the direction of origin and part of its energy.

When a photon interacts with biological material or body tissue, a secondary electron is produced which then gives its energy to the tissue it passes through and the network absorbs the secondary electron energy.

In general, there are three types of photon interactions with material, compton scattering, photoelectric effects, and pair production [4][8].

Attenuation Coefficient

The linear absorption coefficient (μ) is absorption with an absorbent thickness measured in cm. The linear attenuation coefficient (μ) depends on the type of radiation material and energy from electromagnetic radiation absorbed by the material.

The attenuation coefficient mechanism into a material depends on atomic number, material density, material thickness, material hardness or can be expressed using the Beer-Lambert law:

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

With **I** as the radiation intensity after penetrating the material,**Io** as the radiation intensity before penetrating the material, **μ** as the linear attenuation coefficient and **x** as the thickness of the material [5].
The linear attenuation coefficient describes the fraction of a beam of gamma-ray light or X-rays that are absorbed or spread to each thickness of the unit from the absorbent material [5] [8].

The weakening coefficient is a weakened X-ray beam fraction per unit of absorbent thickness, can be expressed by the equation:

$$\frac{I}{Io} = e^{-\mu x} \qquad (2)$$

Lead Glass

Lead glass serves to protect radiation officers and other electronic equipment from X-ray exposure, but its ability to con tinue the light must be according to the specified standards. As a shield of radiation, this absorption is nothing but the interaction of X-ray radiation with lead-forming glass compounds which results in the transfer of radiation energy to the element. Lead (DS) glass absorption against X-rays can be calculated by the equation [2].

$$DS = (1 - e^{-\mu x})\ x\ 100\ \% \qquad (3)$$

Lead Glass Specifications

Lead Glass that is used as X-ray restraint requires certain specifications and meets the standards of SNI-16-6656-2002 which is about lead glass for X-ray radiation protection [8].

In the standard provisions, it was stated that the absorption of X-ray radiation at a nominal thickness of 1.45cm is equivalent to lead (Pb) 2.75 mm and the translucency of the light should not be less than 80% [7] [2]

ISO standard on lead glass, namely:
Light transmission : ≥ 80 %
Minimum Density : 4,36 g/cm3
: 1,6 gr/cm3 (Lead Acrylic)
Knoop Hardness : 370 kg/mm^2
Torsion Modulus : 24,8 Gpa
Coefficient of Thermal Expantion :80 x 107/^{0}C (300 - 3800)

Polyester Resin

Unsaturated polyester resin or often called polyester is a matrix of composites. This resin is also included in thermoset resins.In thermoset polymers liquid resin is converted into hard and brittle solids formed by chemical crosslinking that forms a strong polymer chain. In fabricating using polyester resin, the resin and other additives are confirmed to have spread evenly before the catalyst is added [3].

Polyester Resin Yukalac C -108B

Yukalac C-1088 polyester resin as matrix material with physical properties of density 1.215 g/cm^3, melting point 170^{0}C, water absorption 0.118% (24 hours), tensile strength 5.5 kg / mm^2, modulus of elasticity 300kg / mm^2 and elongation break 1, 6% [3].

Catalyst

A catalyst is a chemical compound that causes the reaction to be faster to reach equilibrium without experiencing chemical changes at the end of the reaction. Catalysts generally have the following properties: activity, stability, selectivity, age, regeneration and good mechanical strength. In general, catalysts have two functions, namely accelerating the reaction to equilibrium or function of activity and increasing the desired reaction or selectivity function [3][8].

Lead Acetate

Lead or lead is a heavy metal that is naturally present in the earth's crust and is spread to nature in small quantities through natural or artificial processes.
Lead is heavy metal, with atomic number 82, atomic weight 207.9 and specific gravity 11.34, has a melting point 327.5 ^{0}C and boiling point 1740^{0}C [1] [7].

METHODS

The method of making samples and testing the characteristics of radiation shielding in this study was carried out by direct experiment using the blanding method, where polyester resin material was used as matrix and lead acetate as filler material and a catalyst to accelerate the sample curing time.

Data retrieval was carried out by testing physical properties, namely density test, X-ray attenuation and light transmission. Testing of Mechanical properties carried out are Press test and hardness and Thermal properties testing.

The process of making radiation shielding based on polyester resin and lead acetate research samples begins with preparing the equipment needed and the materials needed, namely : Yukalac C-108B polyester resin, lead acetate and MEKPO catalyst (Methyl Ethyl

Ketone Peroxide). The method used in making the radiation shield sample is the Blending method.

Before the poses were made, X-ray radiation shielding samples made from polyeseter resins and lead acetate were first prepared by printing samples from a square aluminum sheet with a size (4 x 5 x 2) cm. In the process of determining the composition of each sample that will be made, then the process of weighing/measuring the radiation shield sample material is carried out in accordance with the variation of the composition of the weight mixture specified.

Before the sample printing process is carried out, homogenizing the material is first done using a magnetic stirrer for 5 minutes.

After the homogeneous radiation shielding material is mixed, the material is poured into the mold that has been provided. In the process of drying and hardening the sample, by entering the sample into the fume hood with room temperature for ± 5 hours.

After each radiation shield sample has hardened, then the sample is removed from the mold for testing.

Radiation shield sample density testing is done by weighing with an analytical balance sheet to get the sample mass value and calculate the volume value of each sample with different sample thickness, using the formula:

Volume = Length x Width x Thickness.

Testing the transparent value of each radiation shield sample was carried out using Lux Meter. The method used is to measure the value of light transmission before the sample, then by giving the same light source to each sample of the radiation shield so that the light transmission value of each sample of the radiation shield is tested, using the formula:

$$DS = (1 - e^{-\mu x}) x\ 100\ \% \qquad (4)$$

Tests on attenuation/absorption of samples against X-rays are carried out directly by using General X-Ray GE brand and the Unfors Ray Safe X2 General detector by referring to Japan Industrial Standard (JIS) Z 4501 or SNI 18-6480-2000 [7].

To find out the value of the compressive strength of the radiation shield sample, it refers to ASTM C 1572 / C1572 M RL / 17. The tool used to test compressive strength is Universal Testing Machine (UTM). The compressive test method with a test sample is a square shape.

The hardness test of the radiation shield sample was carried out using the Rockwell method.

III. RESULTS AND DISCUSSION

The results of sample density testing that have been carried out in this study can be shown in Figures 1 and 2.

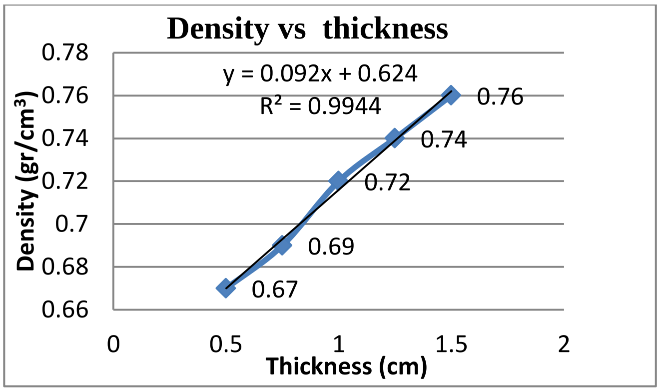

Figure 1: Graph of Density - vs - Thickness of Sample

Based on Figure 1, the value of the sample density increases as the thickness of the radiation shield sample increases. The results showed that the highest density value was 0.76 gr/cm^3 with a sample thickness of 1.5 cm and the lowest sample density was 0.67 gr/cm^3 at a sample thickness of 0.5 cm.

It is concluded that the more the radiation shield sample thickness is made from polyester resin, the sample density will increase.

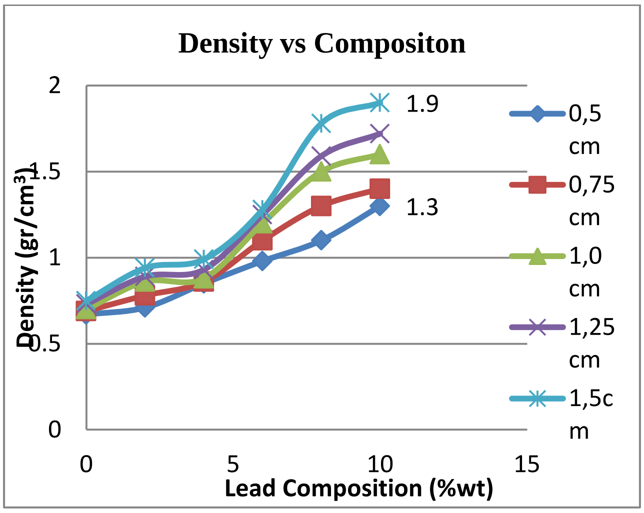

Figure 2: Density Chart - vs - Composition of Acetate

From Figure 2 shows that the density value for each shield sample increases with the addition of the composition of lead acetate. The smallest sample density value is 0.67 gr/cm³ at a composition of 95: 0: 5% wt Pb with a sample thickness of 0.5cm and the largest sample density value of 1.9 gr/cm³ in the composition of 85: 10: 5% wt Pb with 1.5 cm thick is the best sample density value. From the results of testing the radiation shield sample density, it can be concluded that the addition of lead acetate composition as X-ray radiation shield filler and polyester resin base material can increase the sample density value.

When compared with the value of the radiation shield density that has been determined according to ISO Standards on lead glass and lead acrylic, that the density value of the sample in the composition meets the requirements when compared to 1.6 gr/cm³ acrylic lead density.

Absorption Test Results Radiation Intensity

The results of the sample attenuation testing of X-rays that have been carried out in this study are using GE General X-ray aircraft and Ray Safe Unfors detectors with variations in voltage of 40kV, 50kV and 60kV X-ray aircraft can be shown in Figure 3 below :

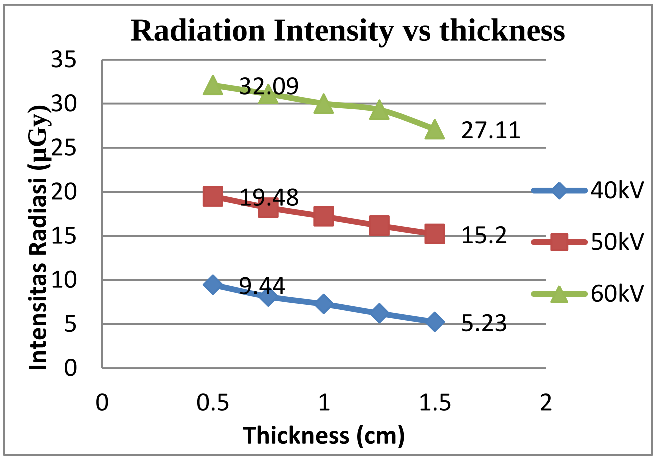

Figure 3: Radiation intensity - vs - Thickness of the sample

Based on Figure 3 shows the results of the attenuation test of radiation radiation samples to the value of the radiation intensity produced for each voltage shows that with the addition of sample thickness can increase the absorption of radiation so that the radiation intensity values are lower. This shows that the thicker the radiation shield sample made from polyester resin, the greater the absorption of radiation, due to the thick function of the radiation shield is inversely proportional to the value of the radiation intensity produced in accordance with Beer Lambert's law. The sample test results of how the influence each radiation shield sample composition on the value of radiation intensity with variations in voltage 40kV, 50kV and 60kV can be seen in the following figure:

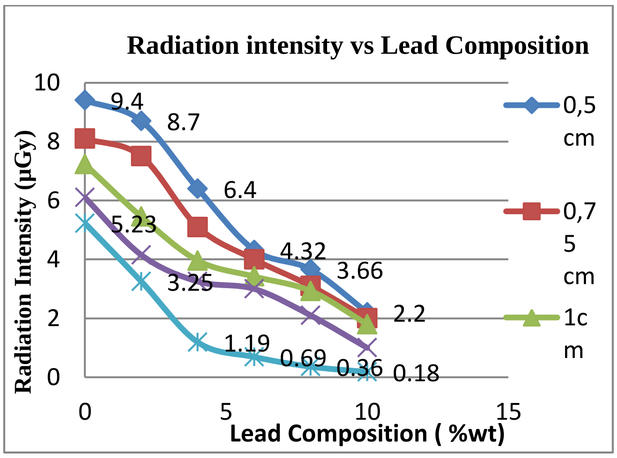

Figure 4: Relationship graph Radiation intensity - vs - Composition Sample voltage 40 kV

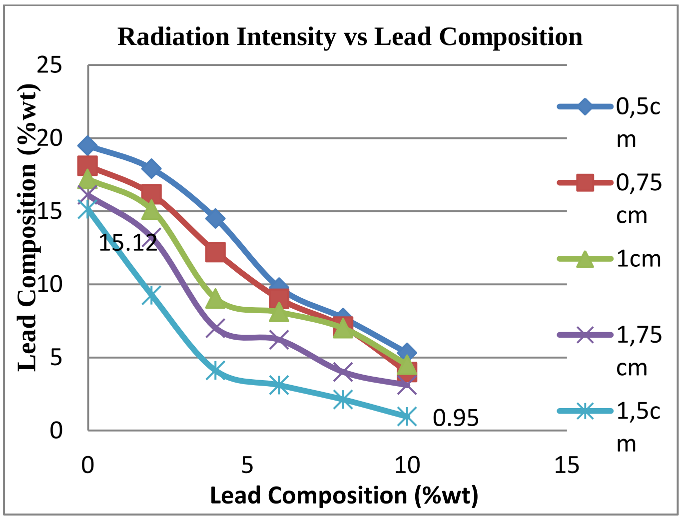

Figure 5: Correlationship graph Radiation intensity - vs - Composition Sample 50 kV voltage

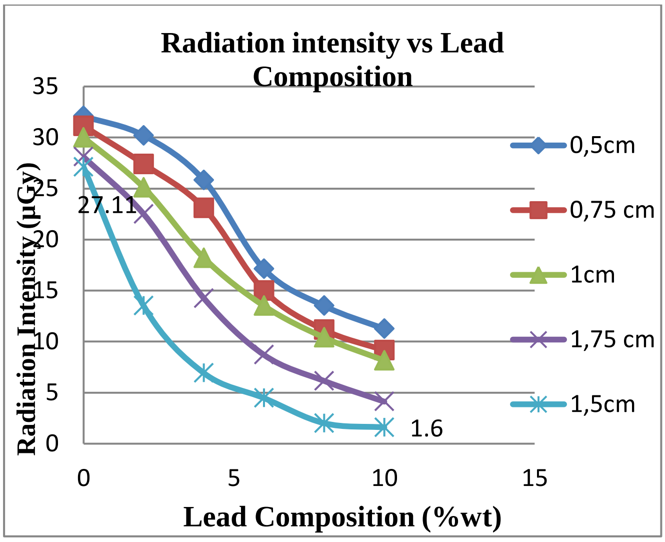

Figure 6: Relationship graph Radiation intensity - vs - Composition Sample voltage 60 kV

From the graph above shows the test results of attenuation of samples on the variation of lead composition (Pb) at each plane voltage of X-rays is 40kV, 50kV and 60kV each radiation shield sample. The largest sample absorption value with the value of radiation intensity for each voltage indicates that the sample thickness of 1.5 cm with a composition of 85: 10: 5% wt Pb is the best value. It can be concluded that the addition of lead acetate can increase the absorption of the sample against radiation.

When compared with lead glass which is commonly used on radiology installations, radiation shield samples with polyester resin base material with the addition of lead acetate have the ability to absorb high radiation.

From the graphs of attenuation testing of radiation shield samples made from polyester resin with variations in thickness and composition of lead acetate showed that the sample at a thickness of 1.5 cm with a com position of 85: 10: 5 wt Pb resulted in the highest absorption rate of radiation.

Percentage absorption of Sampel to X-Ray Radiation

From the results of testing the sample radiation it can be concluded that the percentage absorption rate of radiation for each sample at a voltage condition of 40kV, 50kV and 60kV.

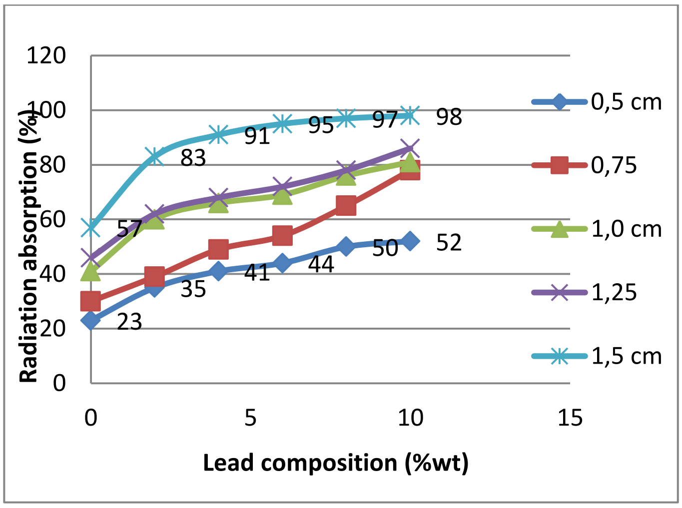

Figure 7: Graph of percentage of radiation absorption - vs. - Sample composition of 40kV voltage

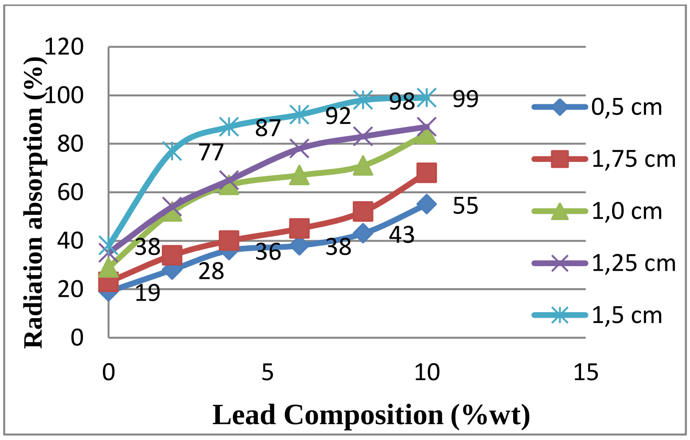

Figure 8: Graph of percentage of radiation absorption - vs. - Sample composition of 50kV voltage

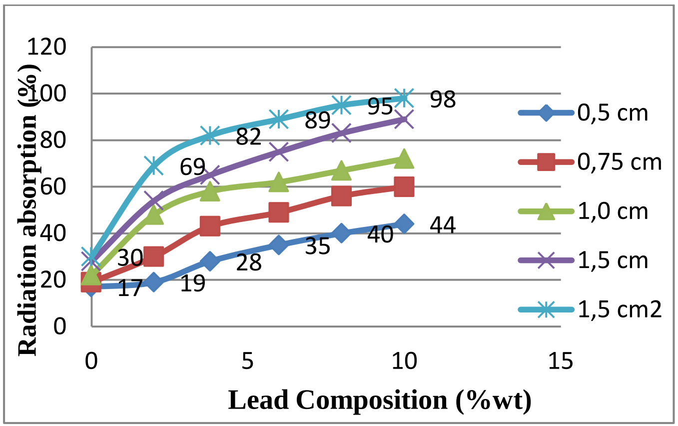

Figure 9: Graph of percentage of radiation absorption - vs. - Sample composition of 60kV voltage

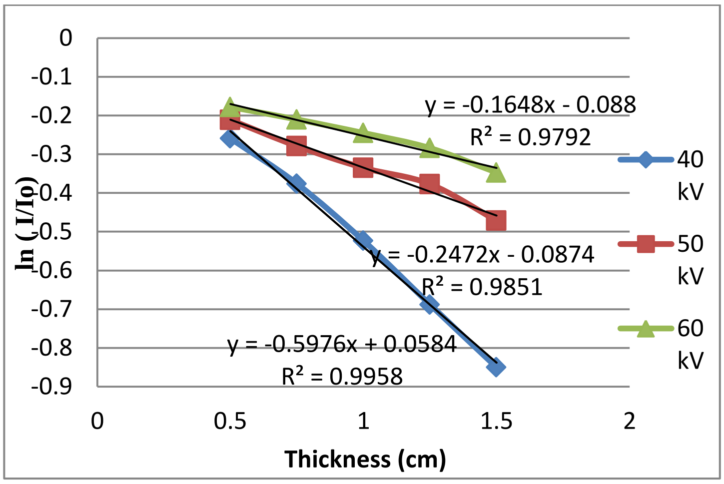

Figure 10: Graph of relationship of ln (I / Io) absorption of Radiation - vs - thickness of the sample

From the graphic picture of the percentage of sample absorption against radiation shows that the sample composition of 85: 10: 5% wt Pb with a sample thickness of 1.5cm shows the highest percentage of radiation absorption percentage is 98% - 99% and the lowest value is in the sample without lead composition. This shows that the radiation shield sample is at a thickness of 1.5 cm, made from polyester resin with lead acetate alloy which can increase the highest X-ray absorption up to 98% - 99%.

Linear absorption coefficient (μ)

Radiation uptake testing has been carried out on the radiation shield sample to determine the linear attenuation coefficient (μ) with variations in material composition and sample thickness at 40kV, 50kV and 60kV. Testing the absorption value of materials against X-ray radiation is done by using GE general-X-ray aircraft and Raysafe detectors.

The results of testing the relationship of linear attenuation coefficient (μ) to the sample composition can be shown in Figure 10.

From Figure 10, it can be seen that the relationship of radiation absorption with variations in sample thickness to the value of ln (I/Io) produces a decreasing value. From the results of the relationship of ln (I/Io) absorption of radiation to the thickness of the sample indicates that the value of the absorption of X-rays is higher as the thickness of the radiation shield sample increases.

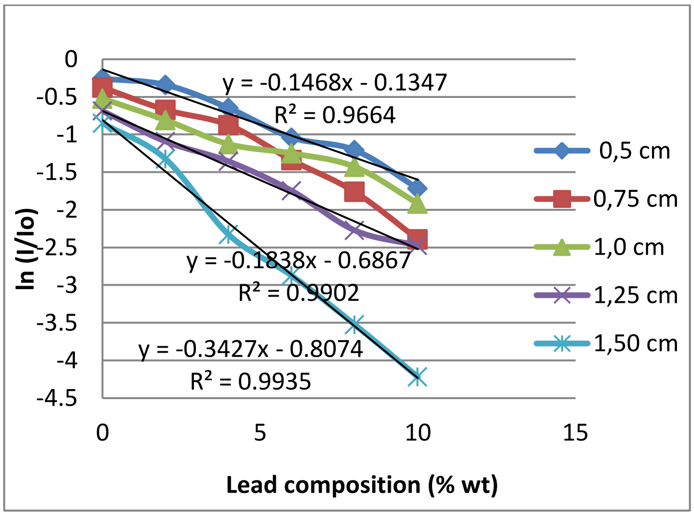

Figure 11: Graph of relationship of ln (I / Io) absorption of Radiation - vs - Composition of Samples at a voltage of 40 kV

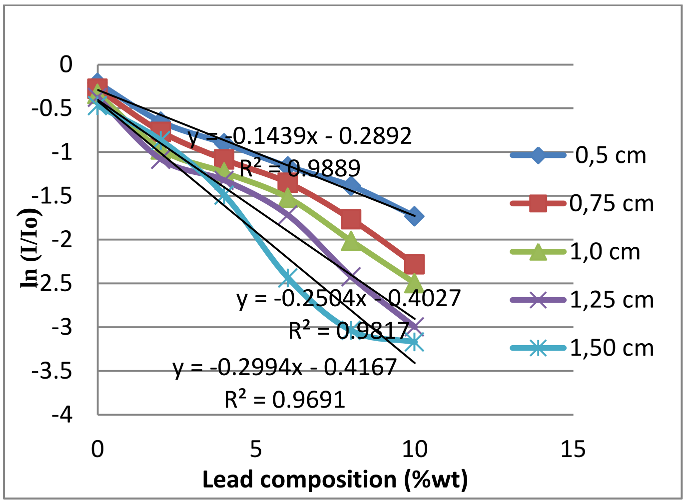

Figure 12: Graph of relationship of ln (I / Io) absorption of Radiation - vs - Composition of Samples at a voltage of 50 kV

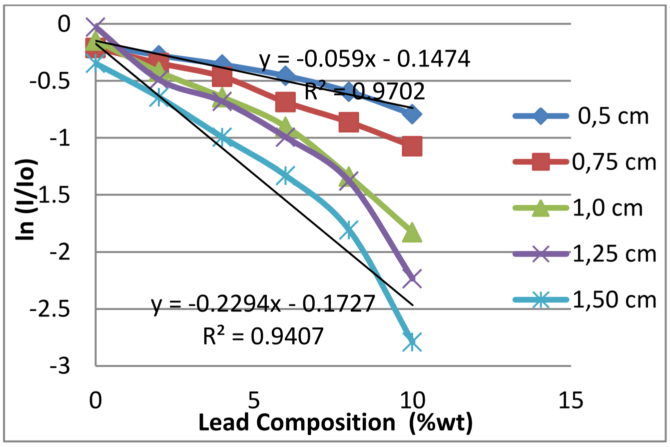

Figure 13: Graph of relationship of ln (I / Io) absorption of Radiation - vs - Composition of Samples at a voltage of 60 kV.

From the graphs of the results of sample absorption of X-rays for each stress condition and the relationship of ln (I / Io) values, it shows that the values of ln (I / Io) decrease with increasing thickness and composition of Pb acetate for each sample, and vice versa when thick and the composition of lead acetate decreases, the X-ray that is passed on the sample increases.

The graph shows that the material attenuation coefficient value (μ) increases with the increase in the composition of lead acetate in each sample. The greatest attenuation coefficient value is 2.4 gr / cm^{-1} at a composition of 85: 10: 5% wt with a thickness of 1.5cm while the lowest value is 0.23 gr /cm^{-1} at a composition of 95: 0: 5% wt with 0.5cm thick.

From the graph above, it can be seen that the role of lead acetate for polyester resin radiation shields is very influential on the material absorption coefficient so that with the increase in the composition of lead acetate, the ability to absorb radiation is higher.

Light Transmission

Testing of the light transmission in each sample of the radiation shield is carried out using an LED medical lighting source with a Lux meter light transmission measuring instrument. The test results of light transmission can be shown in the following figure.

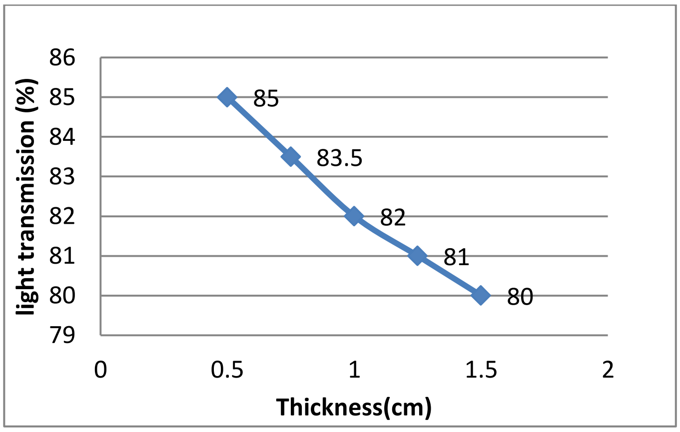

Figure 14: Graph of the relationship of transmission of light - vs - thick samples

From Figure 14, it can be seen that the value of light transmission which is passed after passing through a shield sample of polyester resin has decreased the value of light transmission along with the increase in the thickness of the sample. The highest light transmission value is 85% at 0.5cm sample thickness and the lowest light transmission value is at 80% with a sample thickness of 1.5cm.

This shows that with increasing sample thickness, the value of light transmission produced decreases, influenced by the greater light absorbed by the sample, but in samples with a thickness of 1.5 cm the value of light transmission is still in accordance with the provisions of ISO standards on lead glass.

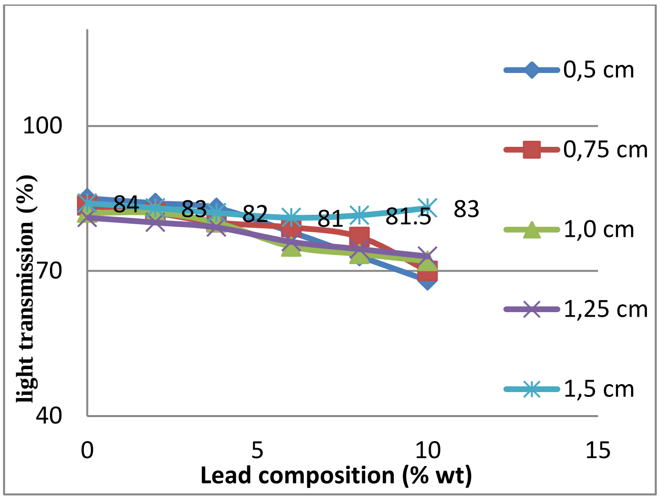

Figure 15: Graph of the relationship of light transmission - vs - sample composition

From Figure 15, it can be seen that the value of light transmission that can be passed after passing through each shield sample of polyester resin radiation has decreased the value of the light transmission proportional to the addition of the sample composition.

The highest light transmission value is 85% with a sample thickness of 0.5cm, but this sample does not meet the requirements as a radiation shield and the next highest light transmission value is 83% with a sample thickness of 1.5cm at a composition of 85: 10: 5% wt Pb where this sample fulfills the requirements as a radiation shield, because in testing the radiation absorption of this sample has a high absorption.

The lowest light transmission value is 85: 10: 5% wt with a sample thickness of 0.5cm. This is because lead dissolves with polyester resin which causes the transparent level of the sample to decrease so that the absorbed light increases.

Press Strength

The compressive strength test for each sample of the radiation shield was carried out using the Maekawa Testing Machine test equipment. The compressive strength test results can be shown in the following figure.

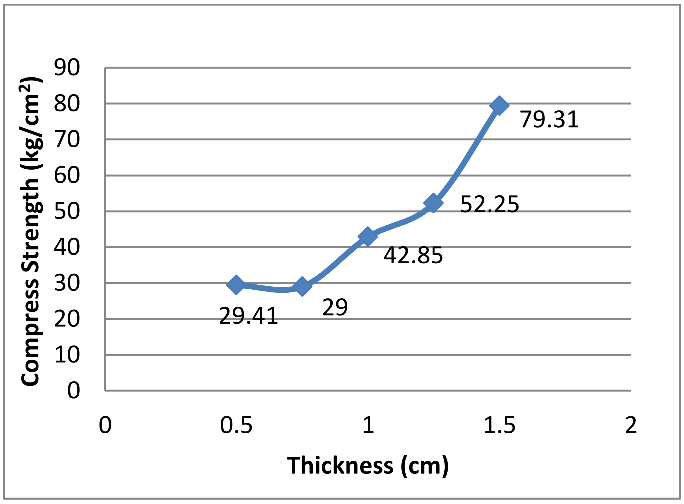

Figure 16: Graph of compressive strength - vs - thickness of the sample

From the graph, it can be seen that the sample compressive strength is greater as the sample thickness increases. In the radiation shield sample with a thickness of 1.5 cm is a sample that has the largest compressive strength of the other samples which is 79.3 kg / cm².

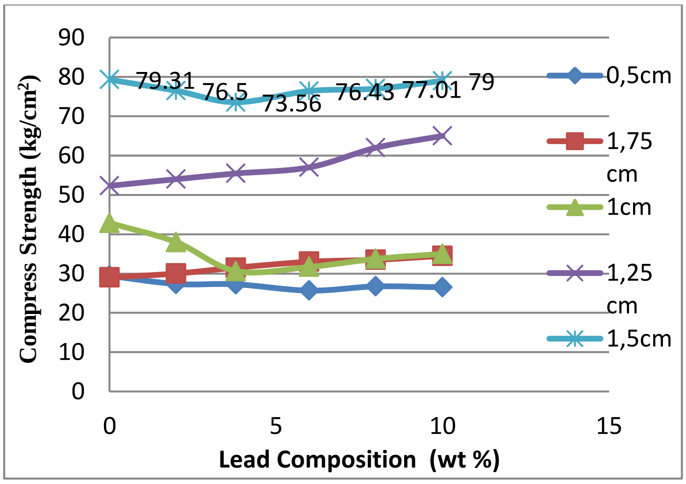

Figure 17: Graph of compressive strength - vs - sample composition

From Figure 4.17 it can be seen that the compressive strength of the sample after adding the composition of lead acetate has decreased compared to the sample before added with lead acetate. This is because the larger the pores on the radiation shield sample, so that the binding capacity between polyester resin material and lead acetate decreases. However, when viewed from the function of the sample as a radiation shield the compressive strength value that is produced has met the requirements.

Hardness Test

Hardness testing of radiation shield samples has been carried out for thick variations and composition. Hardness testing of samples was carried out using the Rockwell method. Hardness testing results can be shown in the following figure.

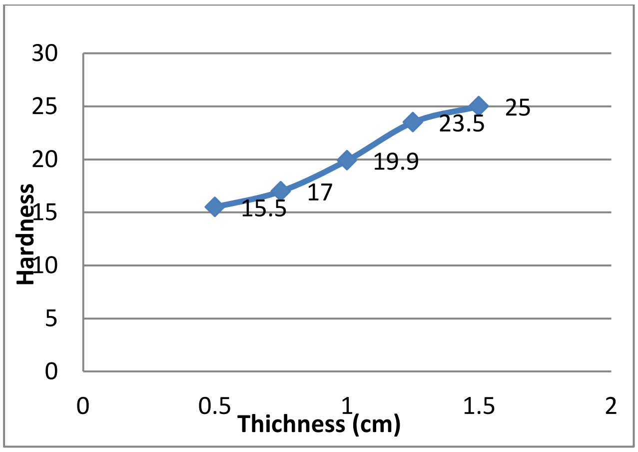

Figure 18: Test graph of sample hardness - vs - Thickness of sample

From Figure 18 it can be seen that the hardness value of the sample is higher as the thickness of the radiation shield sample increases. The value of the difference in hardness with the thickness variation of the sample has a very far difference because when testing the sample with the rockwell method at three different points for each sample has an uneven value. This is due to different sample homogeneity.

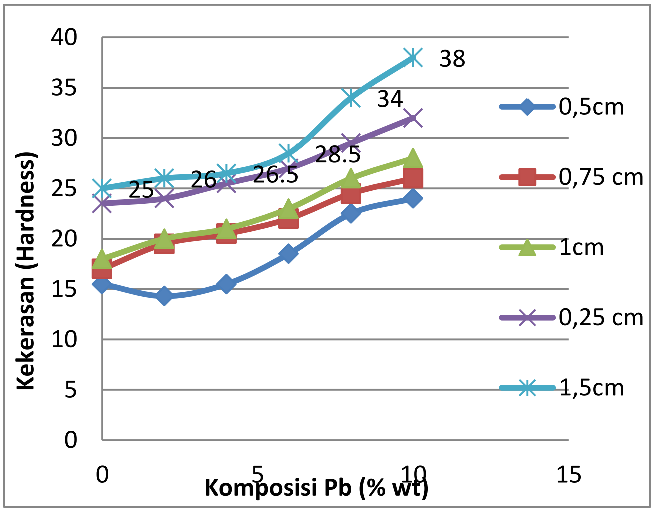

Figure 19 : Test graph of sample hardness - vs - Thickness of sample.

From the graph above, it can be seen that the hardness value of the sample has an increase in the value of hardness but not too significant when compared to the results of hardness testing of samples without the composition of lead acetate.

So that the graph of the hardness relationship of the sample after the addition of the composition of lead acetate does not show a significant difference in the value of violence.

Thermal Test

Thermal testing of samples was carried out at 1.5 cm thickness in composition (95: 0: 5)% and (87: 10: 5) wt% using Differential Scanning Calorimetry (DSC). Thermal test results can be shown in the following figure.

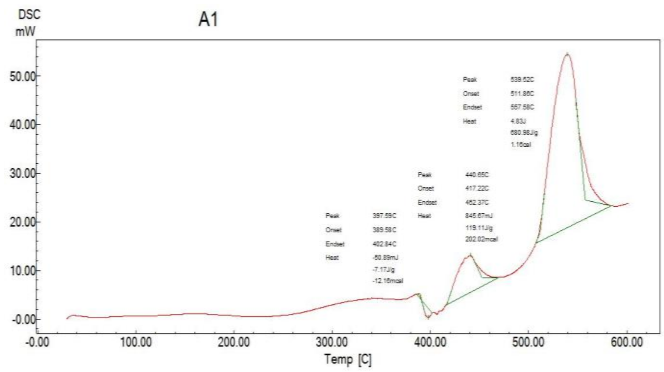

Figure 20: Graphs of DSC Testing on composition samples (95: 0: 5)% wt lead

From Figure 19 the thermal test results show that the composition radiation shielding sample (95: 0: 5)%, shows an endothermic event where the initial temperature is at $389,58^0$ C, the temperature of the spike is $397,59^0$C and the final temperature is at $402,84^0$C.

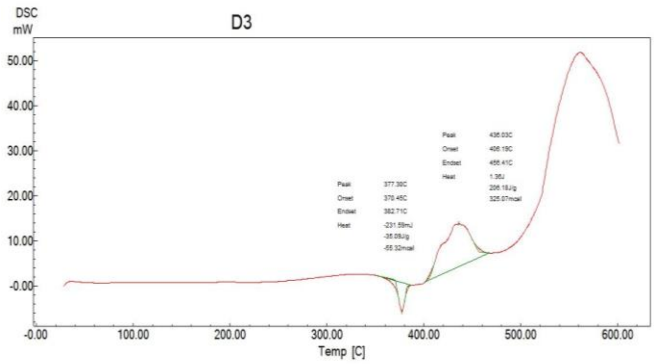

Figure 20: Graph of the results of DSC testing on composition samples (87: 10: 5)% wt lead.

In Figure 20, it can be seen that the composition radiation shielding sample (87: 10: 5)% wt Pb, shows endothermic events by showing the glassy properties of the radiation shield sample after adding the composition of lead acetate, where the initial temperature is $370,45^0$ C, peak temperature $377,30^0$ C and the final temperature is at 382.7^0C this also shows the presence of melting solids in the sample.

By looking at the results of the thermal test graph on the two radiation shield samples, it shows that the peak temperature of $377,30^0$C for samples in composition (87: 08: 5)% meets the requirements according to the ISO standard of lead glass to be used as a radiation shield.

IV. CONCLUSION

Based on the results of data analysis, some conclusions can be drawn, including:

1. From the results of the physical examination of the radiation shield density of polyester resin and lead acetate, the best density value is 1.9 gr / cm^3. Density increases with thick variations and composition. When compared with the ISO standard on lead and acrylic lead glass, the density value meets the requirements.
2. The test results of sample absorption against X-rays radiation intensity relationship graph shows samples with a thickness of 1.5cm capable of absorbing 98%, 99% and 98% radiation under voltage conditions of 40kV, 50kV and 60kV which in graphical form appear to be exponentially proportional inverse radiation intensity to thickness and composition of lead acetate.
3. Graph of relationship of ln (I/Io) absorption of radiation with the function of linear attenuation coefficient of material (μ) shows the value of radiation intensity decreases along with the value of linear material attenuation coefficient (μ) which increases.
4. Light transmission values in each radiation shield sample with thick variations and sample composition showed a decrease in the transparent value, but the 1.5 cm sample with composition (87: 10: 5) wt% had a light transmission value of 83% and still fulfilled the requirements according to ISO standard on lead glass.
5. The results of mechanical testing of the value of the compressive test and hardness test of the sample increases, along with the addition of filler and thickness of the sample. In DSC testing of two samples with composition (95: 0: 5)%, where the initial temperature is at $389,58^0$C, peak temperature is $397,59^0$C and the final temperature is at 402,840C.

   Whereas in the composition (87: 08: 5)% the initial temperature is at 370.45^0 C, the temperature is $377,30^0$ C and the final temperature is at 382.7^0C.

   Of all tests that have been carried out both physical, mechanical and thermal tests show that samples that meet ISO standards regarding lead radiation glass shields are 1.5 cm thick with a composition of 87: 10: 5% wt leBad.

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