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Lead-polyester resin composite as an alternative material for radiation protection in radiography

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Lead-polyester resin composite as an alternative material for radiation protection in radiography

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Abstract. This work presents synthesization and characterization of polyester resin doped with lead acetate ($\text{Pb}(\text{CH}_3\text{COO})_2$) as an alternative material for radiation protection in radiography. Five samples were synthesized with various lead concentration which are 0%, 3.5%, 3.75%, 4% and 4.5%. The samples were characterized using X-ray, He-Ne laser, and FTIR. The results showed that as lead concentration was increased, optical density increased while X-ray transmission decreased. It were found that the attenuation coefficients for each samples were 0.132 cm^{-1} , 0.435 cm^{-1} , 0.543 cm^{-1} , 0.691 cm^{-1} , and 1.156 cm^{-1} . In terms of transmission and attenuation coefficient, lead-polyester composite with lead concentration of 3.5% has an optimum performance.

1. Introduction

Radiation protection is a very important aspect in controlling the effect of radiography. Therefore, every nuclear installation and radiology unit must pay attention to radiation protection. Commonly, materials that can be used as shields so that radiation exposure does not spread to undesirable places are concrete, lead, steel, and other heavy materials. Among them, lead has the best performance since it has high atomic number, high density, low cost and easy to be processed [1]. However, the usage of lead causes new problem since lead is toxic that could harm human life and pollute the environment [2][3]. Moreover, lead has disadvantages in terms of low chemical stability, low mechanical strength and low service flexibility [4]. Therefore, numerous efforts have been carried out to reduce the usage of lead in radiation shield such as using polyester steel composite [5], ethylene vinyl acetate [6], poly(methyl methacrylate)/colemanite composite [7] and polyimide composite [8].

In this work, we propose to use polyester resin for radiation shield. Polyester resin was chosen since it is a low cost material with comparable mechanical strength, although it is not as high as that of other resins such as epoxy resin. Polyester resin has been used for various applications such as Braille block [9], particleboard [10] and bridge deck pavement [11]. To improve the radiation protection, the polyester resin was doped by lead. There are various lead compounds as a source of lead such as lead acetate ($\text{Pb}(\text{CH}_3\text{COO})_2$), lead monoxide (PbO) and lead nitrate ($\text{Pb}(\text{NO}_3)_2$). However, lead monoxide and lead nitrate could not dissolve in resin catalyst, high melting temperature, and high cost. Therefore, lead acetate was chosen since it can dissolve in resin catalyst and also low cost.



2. Methods

Polyester-lead composite was made from a mixture of unsaturated polyester resin (Yukalac 157 BQTN-EX) as a matrix material with a density of 1.215 g / cm^3 , melting point of 170°C , water absorption of 0.118% (24 hours), tensile strength of 5.5 kg/mm^2 and modulus of elasticity of 300 kg/mm^2 . To accelerate the reaction, MEKPO (Methyl Ethyl Ketone Peroxide) was used as a catalyst. Samples were made with different concentration of lead acetate which were 0% , 3.5% , 3.75% , 4% and 4.5% . After the samples were mixed homogeneously, the samples were heated above magnetic stirrer at temperature of 50°C for 5 minutes. Then, the composites were poured into mold with thickness of 1 cm . Image of polyester-lead composite for various lead concentrations is depicted in Figure 1.

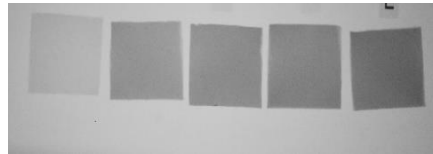


Figure 1. Digital radiography image of polyester-lead composite for various lead concentrations

Characterization in terms of attenuation coefficient (μ), penetrating power (PP), atomic structure and atomic distance were carried out using digital radiography, He-Ne laser and FTIR test, respectively. Attenuation characterization was accomplished by exposing the samples into X-ray resulted from digital radiography equipment with cathode voltage of 50 kV , tube current of 16 mA , shooting distance of 100 cm and exposure time of 0.1 seconds . By observing the incident X-ray intensity (I_0) and the transmitted intensity after penetrating the samples (I), attenuation coefficient can be calculated from the I and I_0 relationship which is defined by

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

where x is the distance travelled by the X-ray. In this case, x is the sample thickness. In this work, I and I_0 were obtained from the grey level (GL) of the X-ray digital image, so equation (1) can be written as

$$GL = GL_0 e^{-\mu x} \quad (2)$$

where GL is the grey level of the sample image and GL_0 is the grey level of the image background. Then, the samples were tested for the penetrating power of light using the He-Ne laser, with variations in the light source for the sample. This test is intended to find the value of the penetrating power of the sample against visible light which is defined by

$$PP = \left(1 - \frac{I - I_0}{I_0}\right) \times 100 \quad (3)$$

To determine the atomic structure and atomic distance of the polyester-lead composite, the samples were characterized using FTIR. The FTIR spectrum of pure polyester and polyester-lead composite were compared to to determine the wavelength band shift.

3. Results and Discussion

The sample images obtained from digital radiography were processed using MATLAB software to determine the grey level. GL was obtained by observing the grey level in the center of the sample, while GL_0 was obtained from the background. Figure 2 shows the value of $\ln (GL/GL_0)$ for samples with various lead concentration. The attenuation constants were calculated using Equation (2). It was found that there is an increase in attenuation coefficient as lead concentration increased. The attenuation coefficient was 0.1323 cm^{-1} , 0.4358 cm^{-1} , 0.5433 cm^{-1} and 0.6913 cm^{-1} , 1.1561 cm^{-1} for pure polyester, with lead of 3.5% , 3.75% , 4% and 4.5% , respectively.

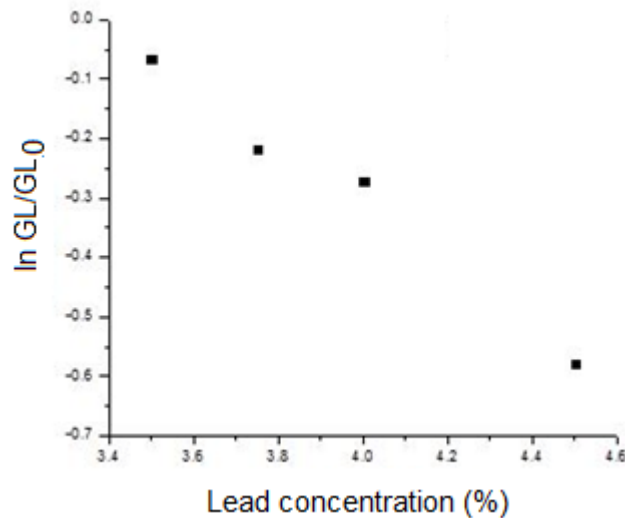


Figure 2. $\ln (GL/GL_0)$ for samples with various lead concentration.

Penetrating value was obtained by exposing the samples to He-Ne laser for various thickness range from 1cm to 6 cm. It is shown that PP decreased as lead concentration increased. The highest decrease was found in sample with lead concentration of 4.5%. This was occurred since the light experienced considerable scattering due to the high lead content.

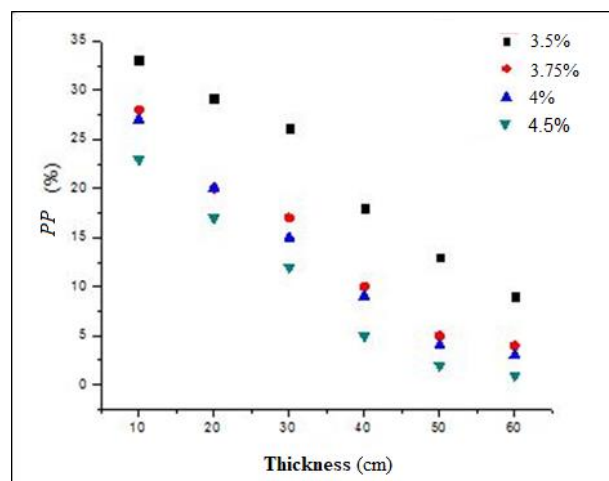


Figure 3. Penetrating power for samples with various lead concentrations and various thicknesses.

FTIR analyses small interactions between atoms of a material, better known as Van der Waal interactions. Interactions can be known by knowing the change in energy when other atoms approach. After adding lead acetate, there are some shifts in the polyester polymer chain. This is possible because of the Van der Waals interaction between the main groups of polymers with lead acetate. It can be seen in Figure 4 that the wave number of CO group is shifted from 1123.71 cm^{-1} to 1123.82 cm^{-1} . This is possible because of the interaction of C atoms in polymer groups with O atoms in the lead acetate chain, as shown in Figure 5. Using the Lennard-Jones equation, it were found that the equilibrium distance, minimum distance and maximum distance between the atoms are 3.69 \AA , 3.29 \AA and 10.19 \AA , respectively. It is known that the wavelength of X-rays with an exposure of 50kV is 0.24 \AA . This value is smaller than the distance between atoms. Therefore, there will be no diffraction when the X-ray penetrates the sample. Diffraction should be avoided since it causes X-rays escape from the gap between the atoms.

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