Jurnal Sains Nuklear Malaysia, 2017, 29(2): 44 – 51
*ISSN: 2232-0946*

# MEASUREMENT OF MASS ATTENUATION COEFFICIENTS FOR CORN STARCH BONDED *Rhizophora* spp. PARTICLEBOARDS AT 16.59 -25.26 keV PHOTONS USING X-RAY FLUORESCENCE CONFIGURATION

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## *ABSTRACT*

*The particleboards were fabricated using Rhizophora* spp. *wood particles with particles size less than 74 µm. The corn starch was used as a bio-adhesive in the fabrication of Rhizophora* spp. *particleboards. The corn starch bonded particleboards were fabricated at 5% and 10% corn starch based on dry mass of Rhizophora* spp. *wood particles. The measurement of mass attenuation coefficients of the particleboards were made at low and intermediate photon energies. The mass attenuation coefficient at low photon energy was measured using X-ray fluorescent (XRF) configuration based on attenuation of $K_{\alpha 1}$ X-ray energies between 16.59 and 25.26 keV given by niobium, molybdenum, palladium and tin metal plates. The calculated mass attenuation coefficients of samples were compared to the theoretical values mass attenuation coefficients of water calculated using the photon cross-section database (XCOM). The results showed that mass attenuation coefficients of 10% corn starch added Rhizophora* spp. *particleboards were in good agreement of water within 7.96 and 4.94% for 5% and 10% corn starch Rhizophora* spp. *Particleboards, respectively compared to 14.57 and 16.16% in binderless Rhizophora* spp. *particleboards and raw Rhizophora* spp. *wood, respectively.*

**Keywords:** Corn starch, mass attenuation coefficient, photon, *Rhizophora* spp. particleboard, X-ray fluorescence

## INTRODUCTION

Phantom is a material that simulates the attenuation properties of human tissue used in quality control and radiation dosimetry works (Attix, 1986; Khan, 2010). Water had been commonly used as phantom material for dosimetry works involving ionizing radiations due to its similarity in absorption and scattering to the human tissues. Phantoms can be considered tissue equivalent when it has radiation properties similar to the tissue include physical density, relative electron density and elemental composition (ICRU-44, 1989; Andreo et al., 2000). To date, studies had been carried out to develop alternative phantom materials which are readily available, economic and environmental friendly. *Rhizophora* spp. mangrove has been identified as potential alternative phantom material due to its density and effective atomic number is near to water (Che Wan Sudin, 1993). The solid *Rhizophora* spp. wood was found to exhibited radiographic properties and mass attenuation coefficients in agreement with water (Bradley *et al.*, 1991; Tajuddin et al., 1996). However, the use of raw wood had some limitations to be used as phantom including limited trunk diameter, difficult in controlling the density, and tendency to crack and warp through drying process. An earlier study had suggested the *Rhizophora* spp. wood to be grounded into small size of particles and compressed into particleboards (Marashdeh et al., 2011). Particleboards can be fabricated without adhesive materials known as binderless particleboard and with addition of adhesive or additive. In another study of attenuation properties of binderless *Rhizophora* spp. particleboards by Marashdeh et al. (2012), the fabricated particleboards were able to retain their similarity of mass attenuation coefficients to the value of water and raw *Rhizophora* spp. wood. The fabrication of particleboards however had reduced the physical and mechanical properties in comparison to the raw *Rhizophora* spp. wood. Marashdeh et al., (2011) also reported that the smaller particles size improved the physical characteristic of the binderless *Rhizophora* spp. particleboard but still failed to meet the readily available industrial standards for particleboards.

Several studies have been carried out on the use of adhesive materials in the fabrication of the *Rhizophora* spp. particleboards to improve quality of particleboard. The wood adhesive are classified into two group based on their sources; synthetic and bio-based adhesive. Synthetic adhesives such as formaldehyde-based are commonly used in particleboard industry due to its fast curing time, clear color and low cost (Pizzi, 2003). However, the use of synthetic adhesive is formaldehyde emission that causes health problems and air pollution (Hashim et al., 2011). The mass attenuation coefficients of the *Rhizophora* spp. particleboards using formaldehyde-based adhesive were significantly varies with the value of water (Surani, 2008; Ngu, 2009). The use of biological-based adhesive or bio-adhesive materials had been studied to fabricate *Rhizophora* spp. particleboards with better physical and mechanical properties and at the same time retain their attenuation properties on ionizing radiations (Abuarra et al., 2014; Tousi et al., 2014; Mohd Yusof et al., 2015; Ababneh et al., (2016). The bio-adhesive were found to improve the physical properties of the particleboards and retained the attenuation properties of *Rhizophora* spp. particleboards in comparison. To date, studies are carried out to fabricate the optimum physical and mechanical properties and improving the radiological characteristics of the particleboards as phantom materials in ionizing radiation applications.

Corn starch had been used as an adhesive material in particleboard industries (Liu et al., 2012; Moubarik et al., 2010; Moubarik et al., 2012). The chemical composition of corn starch is similar to the human tissue with chemical formula of $C_{27}H_{48}O_{20}$. Therefore it is postulated that the addition of corn starch will retain the attenuation properties of the fabricated particleboards. Corn starch consists of complex carbohydrate chains of amylase and amylopectin, linked by glucose units. The breakdown of the sugar during the hot pressing provides the bonding between the wood particles. This study focused on the fabrication of Rhizophora spp. particleboards bonded with corn starch as a phantom and its mass attenuation coefficient at low energy photons between 16.59 and 25.26 keV.

## MATERIALS AND METHODS

### Sample Preparation

The *Rhizophora* spp. wood trunks were obtained from a mangrove reserve forest in Kuala Sepetang, Perak, Malaysia. The *Rhizophora* spp. trunk were cut into smaller segments and reduced to wood chips by using a planner machine. The wood chips were ground into smaller particles size by using a grinder machine. The wood particles were segregated using horizontal screening machine to obtain particles with ≤ 74 µm size ranges based on the available mesh size. The particleboards were fabricated at target density near to the value of water (1.0 g/cm$^3$). Particleboards with different treatment level of corn starch (0%, 5% and 10%) were prepared. The fabricated particleboards were cut into smaller sample pieces and their densities were measured using gravimetric method based on their external dimension.

**X-Ray Fluorescent Configuration**

The X-ray fluorescent (XRF) configuration was used to measure the mass attenuation coefficients. An annular $^{241}$Am source was used in conjunction with niobium (Nb), molybdenum (Mo), palladium (Pd) and tin (Sn) to produce $K_{\alpha 1}$ photons with energies between 16.59 and 25.26 keV. The details of the metal plates are presented in Table 1. The intensities transmitted were detected by using a Low-Energy Germanium (LEGe) detector shielded with lead to reduce background and scattered radiations. The particleboard samples were positioned in between collimator and metal plates. Figure 1 shows the experimental set up of XRF configuration in this study. The transmitted photons were collected by spectroscopy amplifier and multichannel analyzer (MCA).

Table 1: The metal targets of niobium, molybdenum, palladium and tin and their $K_{\alpha 1}$ X-ray energies used in the XRF configuration

| Plate | Atomic No. (Z) | Purity (%) | $K_{\alpha 1}$ Energy (keV) |
|---|---|---|---|
| Niobium (Nb) | 41 | 99.8 | 16.59 |
| Molybdenum (Mo) | 42 | 99.9 | 17.46 |
| Palladium (Pd) | 46 | 99.9 | 21.21 |
| Tin (Sn) | 50 | 99.9 | 25.26 |

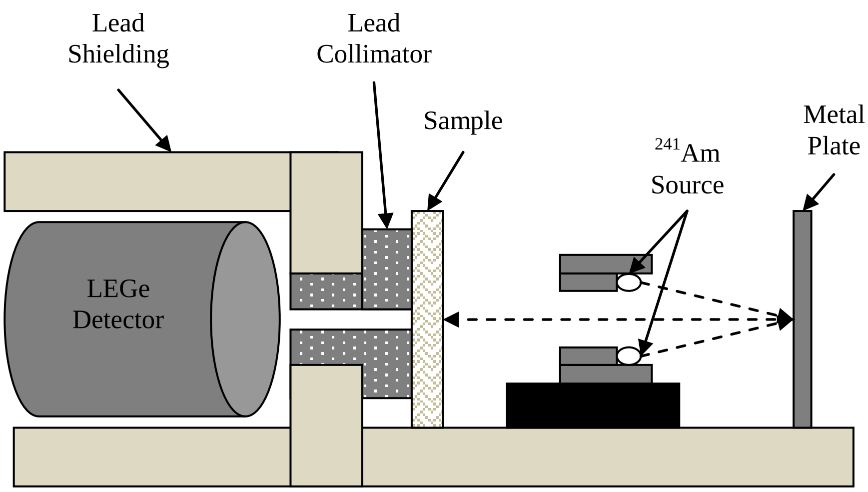


Figure 1: The experimental set-up of XRF configuration used for determination of mass attenuation coefficient of *Rhizophora* spp. particleboards

**Determination of Linear and Mass Attenuation Coefficient**

The attenuation properties were determined by using Beer-Lambert law that stated the beam is attenuated exponentially when passing through materials given by the equation:

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

where $I$ is the transmitted photon intensity, $I_o$ is the photon intensity without attenuation, $\mu$ is the linear attenuation coefficient and $x$ is the thickness. The linear attenuation coefficients were determined by rearranging the Equation 1 into

$$\mu = \frac{\ln I_o/I}{x} \tag{2}$$

The mass attenuation coefficients ($\mu/\rho$) of *Rhizophora* spp. particleboard and raw wood were determined when the linear attenuation coefficients divided by density of the materials. The results obtained were compared to the theoretical values of mass attenuation coefficient of water calculated using the photon cross-section database (XCOM). The percentage discrepancies of the experimental values for samples compared to theoretical value for water at all energies were calculated using equation:

$$Discrepancy\ (\%) = \frac{(\mu/\rho)_e - (\mu/\rho)_t}{(\mu/\rho)_t} \times 100\% \tag{3}$$

where $(\mu/\rho)_e$ is the experimental mass attenuation coefficient of samples and $(\mu/\rho)_t$ is the theoretical mass attenuation coefficient of water.

The paired-sample 2 tailed *t*-test was conducted to evaluate the similarity of the mass attenuation coefficient of *Rhizophora* spp. particleboards and raw wood with mass attenuation coefficient of water. The null hypothesis evaluated was the mean difference between the mass attenuation coefficient of samples and water is zero (Pallant, 2010). The mass attenuation coefficient of a sample was considered statistically equivalent to mass attenuation coefficient of water only if the *p*-value was bigger than 0.05 and the null hypothesis was accepted.

## RESULTS AND DISCUSSION

### Average Density of Particleboards

The average density of *Rhizophora* spp. particleboards measured using gravimetric method is presented in Table 2. The results showed fabricated *Rhizophora* spp. particleboards had achieved the average density near to the value of water (1.0 g/cm$^3$). The particleboards also showed good density uniformities indicated by the low value of standard deviation (SD). These results were in good agreement to previous study by Bradley et al. (1991a) who measured the mass density of raw *Rhizophora* spp. wood. It is postulated that the fabricated *Rhizophora* spp. particleboards in the current study to have similar attenuation properties to water based on the near value of mass density.

Table 2: The average density of *Rhizophora* spp. particleboards measured using gravimetric method

| Particleboard Samples | Average Density ± Standard Deviation |
|---|---|
| 0% corn starch-*Rhizophora* spp.[a] | 1.006 ± 0.005 |
| 5% corn starch-*Rhizophora* spp.[a] | 1.002 ± 0.005 |
| 10% corn starch-*Rhizophora* spp.[a] | 1.004 ± 0.005 |
| Raw *Rhizophora* spp. wood[b] | 1.040 ± 0.002 |

[a]Current study, [b]Bradley et al. (1991b)

**Mass Attenuation Coefficients of Particleboards**

Table 3 showed mass attenuation coefficient of *Rhizophora* spp. particleboards and solid raw wood between 16.59 keV and 25.26 keV photon energies. The percentage discrepancy of the mass attenuation coefficient for samples in comparison to the values of water at 16.59 to 25.26 keV energies is also presented in Table 3. The comparison of mass attenuation coefficients of *Rhizophora* spp. particleboards and raw wood with XCOM value of water is plotted in Figure 2. The results showed that the *Rhizophora* spp. particleboard added with 10% of corn starch gave the lowest percentage discrepancy within 4.94% to the values of water. These results were in good agreement to previous studies by Marashdeh et al. (2012), Abuarra et al. (2014), Tousi et al. (2014) and Mohd Yusof et al. (2015). The solid raw wood samples in the other hand were the least nearest to the value of water with percentage discrepancy between 5.20 and 16.16%. The graph showed that the addition and higher percentage of corn starch gave nearer value of mass attenuation coefficients water. Therefore, the mass attenuation coefficients of the 10% corn starch *Rhizophora* spp. particleboard was more similar to the value of water compared to the binderless and 5% corn starch added particleboards.

Table 3: Mass attenuation coefficients of *Rhizophora* spp. particleboards at 16.59 keV to 25.26 keV photon energies in comparison to water (XCOM)

| Sample | 16.59 keV | | 17.46 keV | | 21.21 keV | | 25.26 keV | |
|---|---|---|---|---|---|---|---|---|
| | μ/ρ ($g/cm^2$) | ±% Dev. | μ/ρ ($g/cm^2$) | ±% Dev. | μ/ρ ($g/cm^2$) | ±% Dev. | μ/ρ ($g/cm^2$) | ±% Dev. |
| 0% Corn Starch-*Rhizophora* spp. | 1.16 | 2.35 | 1.07 | 2.56 | 0.66 | 13.11 | 0.47 | 7.71 |
| 5% Corn Starch-*Rhizophora* spp. | 1.28 | 7.46 | 1.12 | 2.56 | 0.72 | 4.90 | 0.8 | 5.53 |
| 10% Corn Starch-*Rhizophora* spp. | 1.22 | 2.01 | 1.10 | 0.46 | 0.73 | 2.78 | 0.48 | 4.94 |
| Raw Wood *Rhizophora* spp. | 1.13 | 5.20 | 0.92 | 16.16 | 0.66 | 12.98 | 0.44 | 13.04 |
| Water (XCOM) | 1.19 | - | 1.09 | - | 0.76 | - | 0.51 | - |

Jurnal Sains Nuklear Malaysia, 2017, 29(2): 45 – 52
*ISSN: 2232-0946*

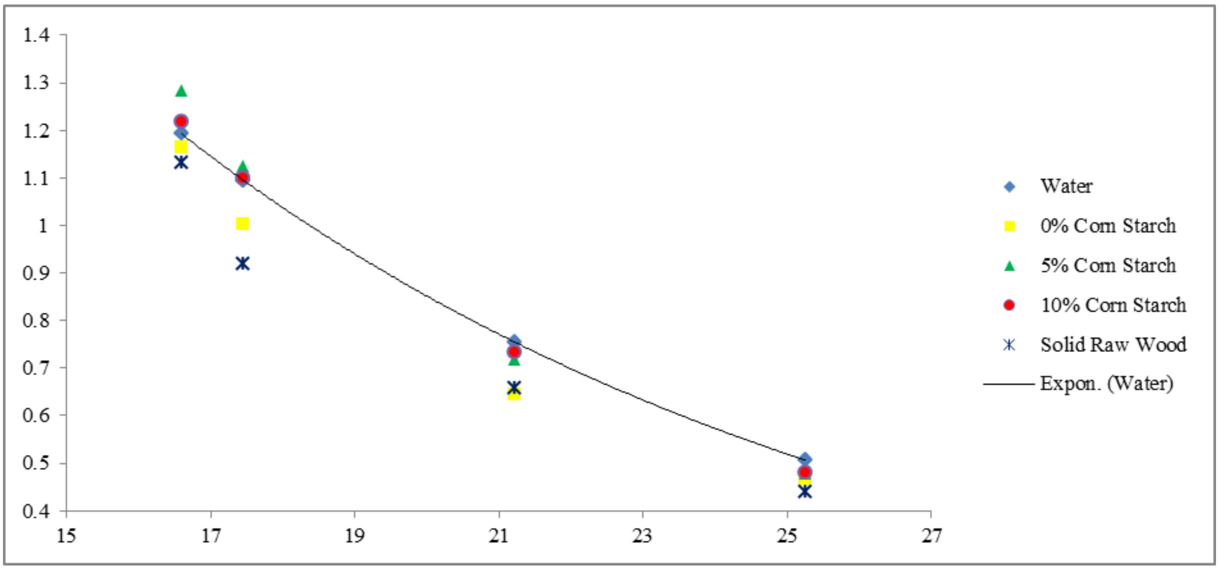


Figure 2: Mass attenuation coefficients of *Rhizophora* spp. particleboards and raw wood

Table 4 showed the results of the paired-sample *t*-test of mass attenuation coefficients of *Rhizophora* spp. particleboards and raw wood with water. The results showed that the pairs of water to 5% and 10% corn starch added *Rhizophora* spp. particleboards were not significantly difference in term of mass attenuation coefficients. Therefore, mass attenuation coefficient of fabricated corn starch added *Rhizophora* spp. particleboards become closer to water by increasing corn starch percentage. This had indicated the similarity of attenuation properties between the corn starches bonded *Rhizophora* spp. particleboards to water. This is consistent with the previous studies on the bio-adhesive based *Rhizophora* particleboards by Abuarra et al. (2014) and Ababneh et al. (2016).

Table 4: The paired-sample *t*-test of mass attenuation coefficients of *Rhizophora* spp. particleboards and raw wood with the theoretical values of water (XCOM)

| **Pair** | **Paired Differences** | | **df** | **t** | ***p*-value (2 tailed)** |
|---|---|---|---|---|---|
| | **Means** | **Std. Dev.** | | | |
| Water – 0% corn starch *Rhizophora* spp. | 0.049 | 0.034 | 3 | 2.848 | 0.065 |
| Water – 5% Corn Starch *Rhizophora* spp. | -0.013 | 0.058 | 3 | -0.446 | 0.686 |
| Water – 10% Corn Starch *Rhizophora* spp. | 0.004 | 0.023 | 3 | 0.369 | 0.737 |
| Water – Raw Wood *Rhizophora* spp. | 0.101 | 0.052 | 3 | 3.779 | 0.032 |

## CONCLUSIONS

The mass attenuation coefficients of 10 % corn starch added *Rhizophora* spp. particleboard were in good agreement to XCOM calculated mass attenuation coefficient values for water at 16.59 to 25.26 keV energies range. These results indicated the addition of bio-adhesive material played an important role in retaining the mass attenuation coefficient of *Rhizophora* spp. particleboards. The overall results had indicated the potential use of corn starch bonded *Rhizophora* spp. particleboards as phantom materials at low energy photons.

## ACKNOWLEDGMENTS

The authors would like to acknowledge Kuala Sepetang Charcoal Factory, Perak for supplying the *Rhizophora* spp. wood trunks. The authors also acknowledge the financial aid of Research University Grant No. PSPTEKIND1000000004178 by Universiti Sains Malaysia.

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*ISSN: 2232-0946*

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