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Fabrication of Formaldehyde-based *Rhizophora spp*. Particleboards and Their Mass Attenuation Coefficients at 15.77, 17.48, 21.18 and 25.27 keV Photon Energies

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Abstract: *Rhizophora spp. particleboards with a target density of 1.0 g cm^{-3} were fabricated from Rhizophora spp. wood particles using formaldehyde resins as binders. Two types of resins, urea-formaldehyde (UF) and phenol-formaldehyde (PF), were used at two treatment levels, 10% and 13%, based on the oven dry weight of the wood particles. The fabricated Rhizophora spp. particleboard samples with 13% PF and 13% UF had densities nearest to the density of water at 0.978 g cm^{-3} and 0.914 g cm^{-3}, respectively. By contrast, the densities of the Rhizophora spp. particleboards at the 10% PF and 10% UF treatment levels were 0.894 g cm^{-3} and 0.885 g cm^{-3}, respectively. The mass attenuation coefficients of the fabricated Rhizophora spp. particleboards were determined using X-ray fluorescence (XRF) beams generated from high-purity zirconium, molybdenum, tin and palladium metal plates. The excitation source used was an annular Am-241 source with an activity of 3.7 GBq. The K_α energy of the XRF emitted from these metal plates ranged from 15.77 keV to 25.27 keV. The mass attenuation coefficient of 10% PF Rhizophora spp. particleboard was the closest to the mass attenuation coefficient of water at these photon energies.*

Keywords: *Rhizophora spp.*, urea-formaldehyde, phenol-formaldehyde, particleboard, mass attenuation coefficient

1. INTRODUCTION

Water is the primary phantom medium recommended for the dosimetry of high-energy photon and electron beams. This is because the measurements of water introduce dose approximations of the values of radiation absorption and scattering obtained for muscle and other soft tissues. In addition, water is universally available and has reproducible radiation properties. However, it poses practical problems when used in conjunction with ionisation chambers and other detectors that are not waterproof. To overcome this problem, solid homogeneous phantoms, such as polystyrene, acrylic and others made from proprietary materials have been introduced and are gaining considerable popularity, particularly in clinical dosimetry.[1] Several studies showed that a type of mangrove wood, *Rhizophora spp.*, possesses similar properties to water-equivalent materials.[2–5] Mangroves are trees and shrubs that grow in saline (brackish) coastal habitats in the tropics and subtropics. The mangrove distribution is circumglobal, with most populations occurring between the latitudes 30°N and 30°S.[6] Shakhreet et al.[7] determined the mass attenuation coefficient of raw natural *Rhizophora spp.* wood and found that it was similar to that of young-aged breast (Breast 1).[8]

However, raw wood tends to crack and warp with time. It is also difficult to ensure uniform density throughout a raw wood sample. Shakhreet et al.[9] proposed that the raw *Rhizophora spp.* wood be shredded into particles and then compressed into particleboards using suitable binders or resins. They used phenol-formaldehyde (PF) resin as the binder and fabricated particleboards with densities of 0.65, 0.75, 0.85 and 1.0 g cm^{-3}. They found that the mass attenuation coefficients of all particleboards were close to that of older-aged breast (Breast 3).[8]

The objective of this study was to fabricate *Rhizophora spp.* particleboards with a target density similar to that of water because water is the standard phantom material for the majority of dose measurements, using urea-formaldehyde (UF) and PF resins at 10% and 13% resin treatment levels. The mass attenuation coefficients of the *Rhizophora spp.* particleboards produced were then determined at several photon energies, including 15.77, 17.48, 21.18 and 25.27 keV.

2. EXPERIMENTAL

2.1 *Rhizophora spp.* Particleboard Fabrication

The fabrication of the *Rhizophora spp.* particleboard was similar to that of Shakhreet et al.[9] *Rhizophora spp.* wood chips were ground into smaller particles using a grinder machine with a mesh size of 2 mm. The wood particles were dried in an oven at 105°C until their moisture content reached approximately 10% based on their oven-dried weights.

PF and UF resins (Hexion Specialty Chemicals, Pulau Pinang, Malaysia) were used as binders for the fabrication of the *Rhizophora spp.* particleboards. First, the solid contents were determined by weighing a small amount of the binder in a clean container and heating until a constant cured weight was obtained. This determination also yielded information on the amount of volatiles released during the hot pressing operation. The PF and UF resins had a solid content of approximately 42% and 48%, respectively.

The moisture content of the wood particles and the solid content of the resins were required to determine the amount of wood particles and resins necessary to fabricate particleboards with a target density of 1.0 g cm^{-3} for similarity to the density of water. Other parameters required were the dimensions of the mould, target density, target weight, particle weight, type of resin and resin treatment level, amount of resin, temperature at the time of hot-pressing and pressure applied.

The wood particles were blended with the calculated amounts of resins. The blended particles were formed into a "mat" in using a flat-press process for 21.2 cm × 21.2 cm × 0.5 cm particleboards. The blended furnish was consolidated with a hot press at 140°C and 300 kgf cm^{-2} machine pressure for a given density. As the hot particleboard emerged from the press, preparatory operations, such as cooling, trimming and moisture equalisation, were performed. Each mat was cut into nine identical samples with dimensions of 5 cm × 5 cm × 0.5 cm.

2.2 Density Test

The densities of the particleboard samples were determined by measuring their physical dimensions and weighing. The thickness, length, width and mass were measured to the nearest 0.05 cm, 0.1 mm and 0.001 g, respectively, and the density was calculated to the nearest 0.01 g cm^{-3}.

2.3 Determination of the Mass Attenuation Coefficient of the Fabricated *Rhizophora spp.* Particleboards

The experimental set-up to determine the linear attenuation coefficient was as shown in Figure 1. This set-up was different from that of Shakhreet et al.[7,9] except for the metal plates. A 3.7 GBq (100 mCi) annular Am-241 source was used as the excitation source. The Am-241 was mounted in the recess of a cylindrical lead block. The block had an axial hole such that the generated X-ray fluorescence (XRF) could be projected back to the detector in a 180° backscatter geometry. The distance between the Am-241 source and the detector was 60 cm, whereas the distance between the Am-241 source and the metal plate was 9 cm.

The detector was enveloped in a cylindrical lead shield to reduce background radiation. The detector used was a low-energy germanium (LEGe) detector with a thin Be window connected to a multi-channel analyser (CANBERRA, Connecticut, U.S).

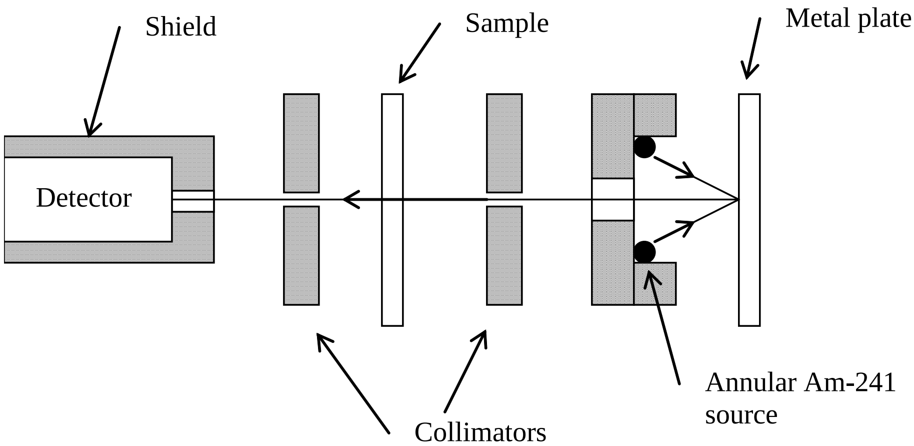

Figure 1: The experimental set-up used for the linear attenuation coefficient measurement of the fabricated *Rhizophora spp.* particleboards using an XRF beam. The shaded parts were made from lead.

Four test samples were randomly selected from the 9 samples cut for each particleboard. High purity zirconium, molybdenum, palladium and tin metal plates were used to produce the XRF K_α energies of 15.77, 17.48, 21.18 and 25.27 keV, respectively.[10] The samples were placed between the 2 lead collimators as shown in Figure 1. The background spectrum was also recorded and was subtracted from the XRF spectra of the samples.

The spectrum of the transmitted XRF K_α beam through the sample was obtained. The value of the net area of the transmitted K_α peak was recorded as I_x. Then, the spectrum without any sample was obtained and recorded as I_o. A graph of $\ln(I_o/I_x)$ versus the thickness of the particleboard was plotted. The gradient of the graph was the linear attenuation coefficient of that particular particleboard for that particular photon energy. The procedure was repeated for the other particleboard samples with 10% UF, 13% PF and 10% PF resins. Then, the metal plate was changed, and the same procedure was repeated for each metal plate.

Finally, the mass attenuation coefficients of the *Rhizophora spp.* particleboard samples with the different resin treatment levels were calculated by dividing the linear attenuation coefficient by the density of the particleboard. Then, the mass attenuation coefficient versus energy was plotted and compared to the calculated mass attenuation coefficient of water using the XCOM computer programme.[11]

3. RESULTS AND DISCUSSION

3.1 Density of the Fabricated *Rhizophora spp.* Particleboard Samples

As shown in Table 1, the density of the fabricated *Rhizophora spp.* particleboard at the 13% PF resin treatment level is the closest to that of water, differing by only 2.2%. Furthermore, the densities of both samples at the 13% resin treatment level were more similar to that of water than those of the 10% samples.

Table 1: Comparison of the densities of the fabricated *Rhizophora spp.* particleboards (target density of 1.0 g cm^{-3}) with regards to the density of water.

Type of fabricated *Rhizophora spp.* particleboard samples	Density (g cm^{-3})	Standard deviation σ	% difference from density of water
10% PF	0.894	0.058	10.6
13% PF	0.978	0.075	2.2
10% UF	0.885	0.034	11.5
13% UF	0.914	0.043	8.6

Note: The standard deviation values were derived from 9 samples for each type of particleboard.

3.2 Mass Attenuation Coefficients of the *Rhizophora spp.* Particleboards

Figure 2 shows that the mass attenuation coefficients of the *Rhizophora spp.* particleboards are dependent on the types of resins used and their percentage contents in the particleboards. There is no clear evidence that increasing the percentage of resin or changing the type of resin used would directly increase or decrease the mass attenuation coefficients.

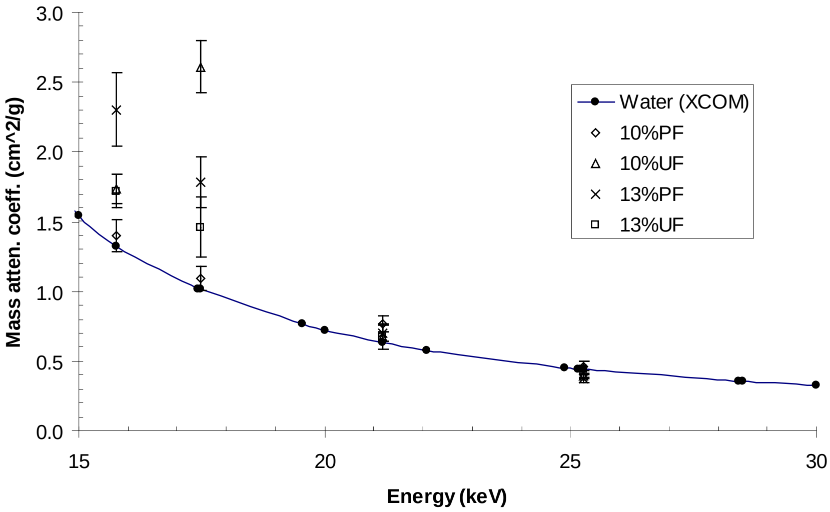

Figure 2: The mass attenuation coefficients of the fabricated *Rhizophora spp.* particleboards at 10% PF, 10% UF, 13% PF and 13% UF resin treatment levels.

Figure 2 also shows the calculated mass attenuation coefficient of water determined using the XCOM computer programme.[11] The figure shows that the mass attenuation coefficients of the fabricated *Rhizophora spp.* particleboards were near the calculated mass attenuation coefficients of water at 21.18 keV and 25.27 keV. However, at energies of 15.77 keV and 17.48 keV, the mass attenuation coefficients of the fabricated *Rhizophora spp.* particleboards deviated significantly from the calculated mass attenuation coefficient of water. The large deviation from the calculated mass attenuation of water in the lower energy region may be caused by the poor intensity of the XRF beam due to instrumental limitations. Future studies should use a high intensity photon source, such as a synchrotron. Nevertheless, the mass attenuation coefficients of the particleboards with 10% PF resin were consistently close to that of water.

4. CONCLUSION

Fabricated *Rhizophora spp.* particleboards with 13% PF and 13% UF resin treatment levels nearly achieved the target water density of 1.0 g cm^{-3}, with densities of 0.978 g cm^{-3} and 0.914 g cm^{-3}, respectively. Therefore, the 13% treatment level with either resin is suitable as a water-equivalent. The mass attenuation coefficients of all *Rhizophora spp.* particleboards were close to the calculated mass attenuation coefficient of water at 21.18 keV and 25.27 keV but not at 15.77 keV and 17.48 keV. However, the mass attenuation coefficients of *Rhizophora spp.* particleboard with 10% PF resin were consistently close to that of water.

5. ACKNOWLEDGEMENT

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