XRF Technique for the Evaluation of Gum Arabic Bonded *Rhizophora* spp. Particleboards as Tissue Equivalent Material

Ali Abuarra, Sabar Bauk, Rokiah Hashim, Sivamany Kandaiya, Ehsan Taghizadeh Tousi, and Baker Ababneh

***Abstract*—For the first time, Gum Arabic (GA) is used as a binder in particleboards preparation and the attenuation properties of the fabricated particleboards were evaluated to check their suitability as tissue equivalent material. Gum Arabic was added into *Rhizophora* spp. particleboards of four particle sizes at three different GA adhesive levels. The X-ray fluorescence (XRF) technique was used to measure the linear and the mass attenuation coefficients of the fabricated particleboards at effective energy range of 17.4 - 26.7 keV. This was achieved by determining the attenuation of Kα1 X-ray fluorescent (XRF) photons from niobium, molybdenum, palladium, silver and tin targets. The results were compared with theoretical values of water calculated using XCOM computer program. The mass attenuation coefficients of the GA bonded *Rhizophora* spp. particleboards were found to be close to the values of water calculated in XCOM at the same photon energies. Luckily, fabricated particleboards showed tissue equivalent results which optimistically can open a new window on the consumption of such a natural adhesive in particleboards as phantom material in dosimetric phantoms and quality control applications.**

***Index Terms*—Attenuation coefficients, gum arabic, particleboards, *Rhizophora* spp, X-ray flourescence.**

I. Introduction

Since the eighties, considerable effort has been employed in the evaluation and characterization of photon attenuation for a wide range of materials [1]. The mass attenuation coefficient of various elements and compounds of biological and dosimetric materials have been treated by some authors, but, many of the so-called tissue equivalent materials fail to provide a good agreement to the mass attenuation coefficient of water at low and high energies [2]. Worth of notice are the efforts made by many other workers in characterizing photon attenuation for wood. For example, considerable research is being focused on the suitability of the mangrove hardwood *Rhizophora* spp. as tissue equivalent phantom material [2]-[8].

According to the previous reports of the *Rhizophora* spp. attenuation properties, particleboards are found better than the raw wood [7]. Despite, binderless particleboards showed good agreement in dosimetric properties with other standard phantom materials in radiation dosimetry, it still not very strong especially in case of internal bond strength and dimensional stability [2]. Moreover, using synthetic binders is to be avoided due to the harmful emissions that threaten health and environment. Therefore, using gum Arabic in this study as a binder in particleboard manufacture might be a suitable substitute to the currently available binders.

In this study, the *Rhizophora* spp. barks and GA are used for the particleboards fabrication. Three different particle sizes of the *Rhizophora* spp. with four GA percentage levels are utilized. The X-ray fluorescence (XRF) technique is used to measure the linear and mass attenuation coefficients of the fabricated particleboards at effective energy range of 17.4-26.7 keV and the results will be compared to the calculated values of water which is often considered as the perfect match for soft-tissue. The attenuation properties of the fabricated particleboards were studied to evaluate their potential as phantom material.

II. Materials and Methods

A. *Rhizophora spp.* Particleboards

The *Rhizophora* spp. trunks were obtained from Kuala Sepatang, Perak, Malaysia. The wood particles were prepared based on Shakhreet *et al*. [8] study with some modifications. The *Rhizophora* spp. trunks were cut into smaller pieces before they were reduced to smaller size by using a surface planner machine (Holy Tek-HP 20, Taiwan). Then, the *Rhizophora* spp. particles were further ground using a grinder machine (Tai-yi model, Retch, Germany), and the last step was repeated for many times to get different particle sizes. After that, a horizontal screening machine with three sieves opening of 210 µm, 149 µm and 74 µm was used to classify the particles according to the particle size into three samples denoted as A, B, and C. Arabic gum powder was also sieved and found to have a size of less than 149 µm.

The GA powder was sprayed onto preweighed quantities of dried *Rhizophora* spp. wood particles in a container with relative percentages of 0%, 5%, 10%, and 15% (w/w) based on oven dried particles weight. Twenty percent (v/w) of distilled water was added. The mixture was then spreaded

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uniformly on a square shape stainless steel plate and bounded with a square stainless steel frame (21 × 21 cm^2) and deckle. The mat was then cold-pressed at 8 kg/cm^2 pressure for about 3 min before hot-pressing at 210°C. The mat was then pressed to the required thickness of 0.5 cm for 7 min. The The boards were then conditioned in an environment of (70 + 5) % relative humidity (RH) and 28 + 2oC before being cut into test specimens and left to cool down. Then, the manufactured particleboard were removed from the frame, trimmed, and cut into 5 cm × 5 cm pieces.

B. Determination of the Linear and the Mass Attenuation Coefficients of GA and Particleboard Samples

The mass attenuation coefficients of the GA and the fabricated *Rhizophora* spp. particleboards were determined by measuring the transmission of the X-ray fluorescent photons through samples of known thickness. The linear attenuation coefficients of all the particleboard samples were determined based on Marashdeh *et al*. [2] set up. The experimental set up in the present work is shown in Fig. 1.

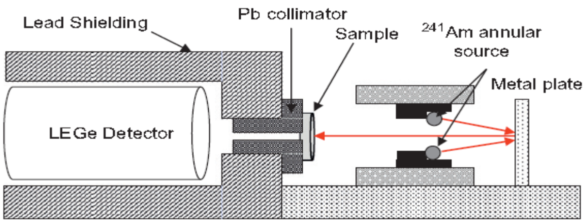

Fig. 1. The experimental set up for the measurement of the linear attenuation coefficients of GA treated *Rhizophora* spp. particleboards using x-ray fluorescence (XRF) beam (Marashdeh *et al*., 2012).

5.0 × 5.0 cm2 GA treated *Rhizophora* spp. samples were irradiated with XRF photon energies. Pure GA samples were prepared in button or disc shape with 1.35 cm diameter and 0.25, 0.41, 0.58, and 0.76 cm thicknesses. Three readings were taken for each sample and the average value of the mass attenuation coefficient of each sample was determined. A 59.5 keV γ-ray of a 100 mCi 241Am annular radioactive source was used to irradiate high- purity metal targets to produce the x-ray fluorescence (XRF) photons. The five metal targets used in this study were Niobium (Nb), Molybdenum (Mo), Palladium (Pd), Silver (Ag) and Tin (Sn) producing Kα1 fluorescent x-rays with effective energies of 17.4, 18.5, 22.4, 23.5 and 26.7 keV, respectively.

The energy intensities were measured using a Low-Energy Germanium (LEGe) detector with an active area and diameter of 200 mm2 and 16 mm, respectively. The crystal is 1.0 cm thick with a resolution (FWHM) of 400 eV at the 241Am 60 keV emission line. The signals were collected into a spectroscopy amplifier and multichannel analyzer. To reduce background and scattered radiations, the detector shielding was designed in the form of a cylindrical lead collimator housing the detector as shown in Fig. 1. The diameter of the collimator was 3 mm. The distances between the metal plate and the sample and between the sample and the detector were 70 and 89 mm, respectively.

As an X-ray beam passes through a sample of thickness x (cm), the intensity of the beam will be attenuated through the absorber according to the Beer–Lambert's law which is given by

$$I = Ioe\_\mu x$$

where *Io* refers to the photon intensity without attenuation; *I* the photon intensity after attenuation. *μ* (cm_1) is the linear attenuation coefficient of the sample material. By rearranging the equation we get

$$\mu = 1 / \times \ln (Io / I)$$

When the linear attenuation coefficient is divided by the density of the sample, we have the density independent mass attenuation coefficient μ /ρ (cm2/g)

$$\mu = 1 / \rho \times \ln (Io / I)$$

where *ρ x* is the area density also known as the mass thickness.

Using Maestro software, the net area of intensity under the characteristic X-ray peak was analyzed and recorded as *Ix*, where *x* is the sample's thickness and the intensity without using any thickness was also recorded as *Io*. The same procedure was done for the GA and the twelve GA treated *Rhizophora* spp. particleboard samples (three particle sizes and four GA percentage levels) using the five different energies. Graphs of ln (*Io* / *Ix*) against thickness were plotted for all samples. The linear attenuation coefficient is the slope of the curve. The mass attenuation coefficient of a particleboard was calculated by dividing the linear attenuation coefficient with the density.

Then, the results obtained in the present study were compared with the mass attenuation coefficient of water [9] calculated using XCOM computer software [10].

III. Results and Discussion

A. Rhizophora spp. Particleboards

The manufactured particleboards had very smooth surfaces and strong rigid texture. The results and specification of the fabricated particleboards are presented in Table I.

TABLE I: Summary of the Manufactured *Rhizophora* spp. Particleboard Samples Bonded with Gum Arabic

Sample	Particle size (μm)	Gum level (%)
A_0		0%
A_5		5%
A_{10}	149-210	10%
A_{15}		15%
B_0		0%
B_5		5%
B_{10}	74-149	10%
B_{15}		15%
C_0		0%
C_5	< 74	5%
C_{10}		10%
C_{15}		15%
Gum	<149	------

B. The Linear and Mass Attenuation Coefficients of GA and GA Bonded Rhizophora spp. Particleboards

The mass attenuation coefficients of the pure GA and the fabricated *Rhizophora* spp. particleboards were also determined in the photon energy range of 17.4–26.7 keV by studying the attenuation of XRF photons from niobium, molybdenum, palladium, silver, and tin targets as presented in Table II. The incident and transmitted intensities of the detected beam were determined from the net counts under the $K_{\alpha 1}$ peak of the XRF spectrum for the metal targets.

TABLE II: THE MEASURED LINEAR AND MASS ATTENUATION COEFFICIENTS OF *RHIZOPHORA* SPP. PARTICLEBOARD SAMPLES AND THE GUM ARABIC DEPENDING ON THE KA1 PEAKS OF THE CHARACTERISTIC X-RAY OF THE METAL TARGETS

Sample	Density,ρ (g/cm³)	μ (cm⁻¹)	μ/ρ (cm²/g)	Error (±%)
Ag (17.4 keV)				
A₀	1.075	1.148	1.068	0.005
A₅	1.192	1.298	1.089	0.004
A₁₀	1.049	1.15	1.096	0.023
A₁₅	1.137	1.271	1.118	0.019
B₀	1.134	0.649	1.005	0.01
B₅	1.095	1.211	1.102	0.048
B₁₀	1.131	1.226	1.083	0.036
B₁₅	1.079	1.226	1.153	0.013
C₀	1.062	1.156	1.089	0.006
C₅	1.201	1.350	1.124	0.028
C₁₀	1.144	1.252	1.094	0.053
C₁₅	1.076	1.260	1.172	0.020
Gum	1.351	1.913	1.416	0.011
Mo (18.5 keV)				
A₀	1.075	1.013	0.943	0.01
A₅	1.192	1.017	0.854	0.106
A₁₀	1.049	1.004	0.957	0.014
A₁₅	1.137	1.116	0.981	0.104
B₀	1.134	0.981	0.865	0.026
B₅	1.095	1.053	0.962	0.004
B₁₀	1.131	1.072	0.947	0.01
B₁₅	1.079	1.023	0.948	0.022
C₀	1.062	1.028	0.968	0.006
C₅	1.201	1.179	0.981	0.026
C₁₀	1.144	1..072	0.937	0.015
C₁₅	1.076	1.128	1.048	0.007
Gum	1.351	1.803	1.335	0.061
Nb (22.4 keV)				
A₀	1.075	0.658	0.612	0.012
A₅	1.192	0.721	0.618	0.035
A₁₀	1.049	0.647	0.617	0.011
A₁₅	1.137	0.693	0.609	0.033
B₀	1.134	0.605	0.573	0.012
B₅	1.095	0.705	0.644	0.009
B₁₀	1.131	0.696	0.615	0.014
B₁₅	1.079	0.676	0.636	0.009
C₀	1.062	0.61	0.659	0.005
C₅	1.201	0.764	0.636	0.016
C₁₀	1.144	0.694	0.606	0.009
C₁₅	1.076	0.728	0.677	0.006
Gum	1.351	1.113	0.823	0.014
Pd (23.5 keV)				
A₀	1.075	0.581	0.54	0.070
A₅	1.192	0.678	0.569	0.069
A₁₀	1.049	0.599	0.571	0.036
A₁₅	1.137	0.653	0.574	0.042
B₀	1.134	0.604	0.532	0.066
B₅	1.095	0.64	0.547	0.008
B₁₀	1.131	0.622	0.55	0.010
B₁₅	1.079	0.656	0.608	0.073
C₀	1.062	0.610	0.574	0.004
C₅	1.201	0.684	0.569	0.005
C₁₀	1.144	0.627	0.548	0.023
C₁₅	1.076	0.691	0.642	0.009
Gum	1.351	0.941	0.697	0.040
Sn (26.7 keV)				
A₀	1.075	0.484	0.45	0.012
A₅	1.192	0.51	0.428	0.021
A₁₀	1.049	0.473	0.451	0.019
A₁₅	1.137	0.489	0.43	0.040
B₀	1.134	0.490	0.432	0.005
B₅	1.095	0.5	0.455	0.013
B₁₀	1.131	0.509	0.449	0.005
B₁₅	1.079	0.542	0.510	0.032
C₀	1.062	0.45	0.424	0.019
C₅	1.201	0.571	0.475	0.010
C₁₀	1.144	0.505	0.441	0.033
C₁₅	1.076	0.517	0.48	0.009
Gum	1.351	0.764	0.565	0.029

The mass attenuation coefficients of *Rhizophora* spp. from the counts under the $K_{\alpha 1}$ XRF peaks of the different particleboard samples as compared with those of water calculated using XCOM were plotted as a graph in Fig. 2.

In the light of the graph above, it was concluded that the mass attenuation coefficient of *Rhizophora* spp. particleboards obtained by XRF technique at photon energies between 17.4 – 26.7 keV were close to the values of water calculated in XCOM at the same photon energies. The mass attenuation coefficients of the *Rhizophora* spp. particleboards for the samples A5, B0, C0, C5, C10 and C15 were close to the calculated value of water which is often considered as the perfect match for soft-tissue. Results of the present study agree with other researchers' findings who studied the suitability of *Rhizophora* spp. as a tissue equivalent material. For example, Bradley *et al*. [3] found that *Rhizophora* spp. wood has tissue-equivalent characteristics which could be consumed to develop a phantom material for radiation dosimetry applications. *Rhizophora* spp. wood was found to be similar to water in terms of both, mass-density and attenuation. In addition, Tajuddin *et al*. [4] found that *Rhizophora* spp. and modified rubber possess scattering and radiographic properties that are similar to water.

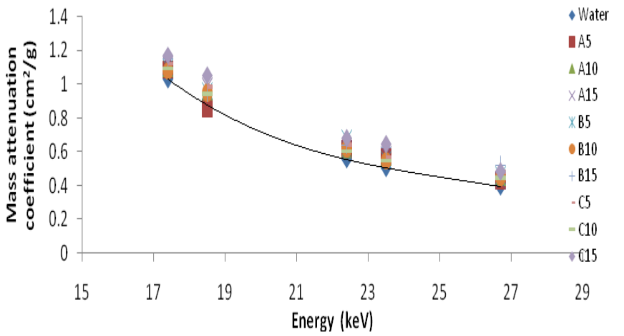

Fig. 2. Mass attenuation coefficients of *Rhizophora* spp. particleboards from the counts under the Kα1 XRF peaks of the different samples as compared with water (calculated in XCOM).

However, B0 and C0 samples which were taken from binderless particleboards and pressed without gum also matched with water. This finding agrees with Marashdeh *et al*. [2], who indicated the significant attenuation properties of the binderless *Rhizophora* spp. particleboards.

In this study, gum was added to the particleboards to enhance their physical and mechanical properties and at the same time retain its attenuation properties. This aim was achieved and it was proved that the gum treated samples A5, C5, C10 and C15 have mass attenuation coefficients which are very close to water in the photon energy range of 15.77–25.27 keV.

IV. Conclusion

Based on the results of this study, particleboards bonded with GA resulted in smoother surfaces and more rigid texture compared to binderless particleboards. The mass attenuation coefficients of *Rhizophora* spp. particleboards obtained by XRF technique at photon energies between 17.4 – 26.7 keV were close to the values of water calculated in XCOM program at the same photon energies. GA bonded particleboards can be recommended to be used as tissue equivalent phantom material for dosimetric applications.

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