Investigation on Suitable Coating Material for Soy-lignin bonded *Rhizophora* spp. Particleboard for Medical Physics Applications

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A phantom material was prepared with different percentages of soy-lignin bonded with *Rhizophora* spp. particleboard and different coating materials, including epoxy resin, gloss wood finish, and a mixture of epoxy resin and gloss wood finish. A set of samples without coating was prepared for comparison. Each sample was bonded with 6% or 12% soy-lignin adhesives. The aim was to investigate the suitability of different coating materials at low energy range. The water absorption, thickness swelling, surface roughness, and mass attenuation coefficients of the samples with various coating materials were examined. Water absorption and thickness swelling of the samples coated with different coating materials followed a similar trend, but only one sample (coated with gloss wood finish) was within the recommended value of 12% according to JIS A 5908 (2003). Surface roughness testing revealed that the sample coated with gloss finish was smoother than other coated and non-coated samples. The mass attenuation coefficient of the sample coated with gloss finish was similar to that of water, indicating its suitability as a coating material for the *Rhizophora* spp. particleboard in medical physics applications.

Keywords: Particleboard; Rhizophora spp.; Coating material; Soy-lignin adhesive; Fabrication

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INTRODUCTION

Tissue-equivalent phantom material is an important tool for dosimetric applications in medical physics. The phantom can be manufactured in the shape of a human body or part of it, with density and radiation interactions similar to that of the actual human tissues (Ramos *et al*. 2017). Tissue substitute materials have been extensively used in experimental dosimetry (White *et al.* 1992). Tissue-equivalent phantom materials must be water-equivalent, as water is the most abundant component of the human soft tissue (Kienbock 1906; White and Constantinou 1982). Water has a mass density value close to that of muscle tissue, with similar radiation properties towards ionizing radiation.

Dosimetric wood-based phantoms have been used for many years, but the variable photon attenuation properties of wood are unclear (Braestrup and Blatz 1940). The linear attenuation coefficient is a physical quantity describing the attenuation properties of a material towards ionizing radiations. It is defined as the ratio between transmitted and initial photon intensities as the photon passes through a medium. This follows the Beer-Lambert's law, *i.e.*, as photon passes through a medium, it is attenuated (Bouguer 1922). Estimation of the mass attenuation coefficient of material for medical physics application is not a trivial task. It encompasses the ability of ionising radiation to attenuate as it passes through different types of materials, thus depending on the characteristics of the material. The mass attenuation coefficient is also important in determining the penetration of photon through matter, as it considers the atomic composition of the attenuator.

Rhizophora spp. in the form of particleboards have been investigated for the fabrication of tissue-equivalent phantom (Sudin *et al.* 1988; Bradley *et al.* 1991; Marashdeh *et al.* 2011; Yusof *et al.* 2017a,b; Zuber *et al.* 2020). The physical and mechanical properties of phantoms for radiation studies have been improved by extensive research (Marashdeh *et al.* 2011; Abuarra *et al.* 2014; Tousi *et al.* 2014). The surfaces of the particleboard specimens are improved by making them smoother, which reduces the moisture content and allows uniform entrance of radiation with less scattering (van Meel *et al.* 2011). Different types of coating materials such as paint, epoxy resin, and gloss finish have been investigated previously (Nemli *et al.* 2005a; Norvydas and Minelga 2006; Rolleri and Roffael 2010; Nzokou *et al.* 2011; Dilik *et al.* 2015; Wang *et al.* 2018).

Epoxy-based materials are commercially available and can be used as coating and adhesive. Those used for surface coating are known to have superior properties, *i.e.*, good mechanical and electrical insulation as well as good chemical and heat resistance. The most common types of epoxy resins are bisphenol A, bisphenol F, and phenoic novolac. Cured epoxy resin has outstanding chemical and corrosion resistance, excellent electrical insulation, high tensile, flexural, and compressive strengths, high thermal stability, and low shrinkage upon cure (Kroschwitz *et al.* 1991; Massingill Jr and Bauer 2000).

Gloss finish is a type of paint or solvent that gives glossy surface and a smooth mirror-like finish. Wood gloss finish provides excellent gloss and durability, great flexibility, and water resistance in all weather conditions. Previous research on the synthesis of polyacrylic resins in water-based coating showed that the coating retains the high gloss finish even under thermal stress (Saeed and Shabir 2013). However, the low-gloss powder coating hardens at lower temperatures (Lee *et al.* 2003). Thus, gloss finish improves the quality of particleboard, especially in terms of thermo-mechanical and archeological aspects (Vardi *et al.* 2010; Modrak and Mandulak 2013; Bekhta *et al.* 2014).

This study focused on the characterization of soy-lignin bonded *Rhizophora* spp. particleboard coated with different coating materials. Water absorption, thickness swelling, and surface roughness tests were performed. The linear and mass attenuation coefficients of the samples with different coating materials were measured. The coatings used in this study were epoxy resin and gloss wood finish, which are commonly used in the wood industry.

EXPERIMENTAL

Materials

Rhizophora spp. wood trunks were obtained from a coal factory in Kuala Sepetang. The trunk was cleaned, dried, debarked, ground, and sieved to produce samples with particle sizes of 0 to 103 µm. Slabs of particleboards bonded with different percentages of soy flour and lignin were constructed at a target density of 1.0 g·cm^{-3}. Table 1 shows the manufacturing condition of the particleboards.

Table 1. Particleboard Manufacturing Conditions

Information	Condition
Raw material	*Rhizophora* spp.
Particleboard size	0 to 103 µm
Target density	1.0 (g·cm^{-3})
Adhesives	Soy flour and lignin
Hot pressing	Temperature: 200 (°C); Time: 20 min; Pressure: 20 MPa
Coating material	Epoxy resin; Gloss wood finish; Combination of epoxy resin and gloss finish

The samples were prepared with dimensions of 5.0 × 5.0 × 0.5 cm^3. Coating materials were epoxy resin (Type E-110I/H-9; Pan Asel Chemicals (M) Sdn Bhd Company, Kuala Lumpur, Malaysia) and gloss wood finish (Wood Finish Glossy D504-1005D; Kansai Paint, Klang, Selangor, Malaysia) obtained from the School of Industrial Technology, Universiti Sains Malaysia. All samples were prepared as shown in Table 2. The epoxy resin was prepared by mixing resin and hardener uniformly by weight with a ratio of 2:1. The sample was mixed and vigorously stirred using an electrical mixer (Pensonic PM-163 Hand Mixer; Pensonic Malaysia, Bukit Minyak, Penang, Malaysia). For samples coated with a combination of epoxy resin and gloss finish, the samples were coated with epoxy resin first and left for 24 h before further coating with gloss finish.

Table 2. Preparation of *Rhizophora spp*. Particleboard Samples With and Without Coating (the percentage of soy flour and lignin are relative to the dry weight of wood)

Sample	Adhesive Percentage (%)	Coating material
A_6	4.5 % soy + 1.5 % lignin	No coating
A_{12}	9 % soy + 3 % lignin	No coating
B_6	4.5 % soy + 1.5 % lignin	Epoxy resin
B_{12}	9 % soy + 3 % lignin	Epoxy resin
C_6	4.5 % soy + 1.5 % lignin	Epoxy resin + gloss wood finish
C_{12}	9 % soy + 3 % lignin	Epoxy resin + gloss wood finish
D_6	4.5 % soy + 1.5 % lignin	Gloss wood finish
D_{12}	9 % soy + 3 % lignin	Gloss wood finish

Methods

Evaluation of linear and mass attenuation coefficients

The linear attenuation coefficient of the fabricated *Rhizophora* spp. particleboard was determined by using X-ray fluorescence (XRF) spectroscopy (Ortec Ametek; Advanced Measurement Technology, Tennessee, USA). The XRF method uses four basic components including radiation source, samples, radiation detector, and analyzing system. Pure metal plates were used to ensure measurement accuracy. Table 3 shows the properties of the metal plate targets (Hamid *et al.* 2017). The radiation source of Americium-241 (^{241}Am) with an activity of 3.7 GBq was used, and the experimental set up is displayed in Fig. 1.

Table 3. Properties of Pure Metal Targets Used in this Study

Metal plate	Atomic Number (Z)	Thickness (mm)	Purity (%)	K_{a1} Energy (keV)
Niobium (Nb)	41	0.14	99.8	16.61
Molybdenum (Mo)	42	0.11	99.9	17.47
Palladium (Pd)	46	0.10	99.9	21.17
Tin (Sn)	50	0.28	99.999	25.27

(Hamid *et al*. 2017)

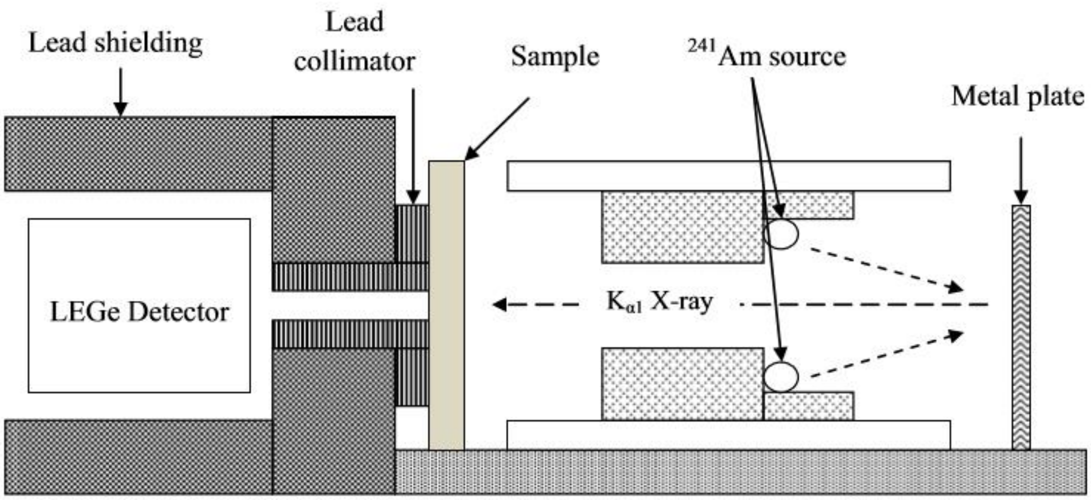

Fig. 1. The experimental set up for the XRF spectroscopy for the measurement of linear attenuation coefficients of *Rhizophora* spp. particleboard

Energy calibration was carried out with an LEGe detector using x-rays and gamma energies associated with ^{241}Am and characteristics x-rays line of niobium, molybdenum, palladium, and tin metal plates. The ^{241}Am point source was placed at 5 cm distance from the LEGe detector. The energy resolution of the detector is calculated to determine the ability of the detector to produce narrow peaks in the spectrum. The energy resolution of the detector can be presented by full width half maximum (FWHM). The energy resolution, R is a dimensional fraction and conventionally expressed as a percentage calculated using Eq. 1,

$$Resolution, R\ (\%) = \frac{FWHM}{E_c}\ x\ 100\ \% \qquad (1)$$

where FWHM is full width half maximum in keV and E_c is the energy at the centre of the peak in keV.

The evaluation of the attenuation coefficient was based on the principle of x-ray fluorescent photon transmission, which penetrates through the sample with known thickness. Four samples of *Rhizophora spp.* particleboards bonded with 6% and 12% soy-lignin adhesives, with dimensions of 5.0 × 5.0 × 0.5 cm^3 and average density equal to 1.0 $g{\cdot}cm^{-3}$ were placed at a distance of 9 cm from the metal plate and 7 cm from the detector and irradiated for 60 s each. The XRF spectrum obtained from the system was analyzed using MAESTRO software (MAESTRO-Pro Ortec Ametek; Advanced Measurement Technology, Tennessee, USA). The transmitted intensity was calculated by Eq. 2,

$$I = I_0 e^{-\mu x} \qquad (2)$$

where I_0 and I are the initial photon and photon intensity, μ (cm^{-1}) is the linear attenuation coefficient of the material, and x is the thickness of the samples. Equation 3 shows the linear attenuation coefficient μ (cm^{-1}) formulation.

$$\mu = \frac{1}{x} ln\left(\frac{I_0}{I}\right) \quad (3)$$

The linear attenuation coefficient was determined by the average value of four readings, and the mass attenuation coefficient was calculated. The results were compared to the mass attenuation coefficient of water provided by XCOM software (NIST database; Gaithersburg, MD, USA), which is based on the elemental composition suggested by previous research (Constantinou *et al.* 1982; Berger and Hubbell 1987). A statistical analysis using a paired sample t-test was conducted to determine the correlation between the measured mass attenuation coefficient of each sample with the theoretical mass attenuation coefficient of water according to XCOM.

Investigation on water absorption and thickness swelling

Water absorption and thickness swelling test were carried out according to JIS A 5908 (2003) for particleboard to determine the dimensional stability of the test sample. The dimension of 5.0 × 5.0 × 0.5 cm^3 test pieces were recorded including the thickness, length, and width using digital caliper pre- and post-immersion in water. The weight of each test piece was measured using an electronic balance. Each sample was immersed in distilled water at 3.0 cm below the water surface. After 24 h, the test pieces were taken out, and excess water was wiped off. The thickness swelling and water absorption after the immersion were expressed in percentages as shown in Eqs. 4 and 5, respectively,

$$Thickness\ swelling\ (\%) = \frac{t_{24} - t_0}{t_0}\ x\ 100\ \% \quad (4)$$

$$Water\ absorption\ (\%) = \frac{WA_{24} - WA_0}{W_0}\ x\ 100\ \% \quad (5)$$

where t_0 and t_{24} are the average thickness before and after 24 h immersion in water, respectively, and WA_0 and WA_{24} are the weights of the sample before and after 24 h immersion in water, respectively.

Investigation on the surface roughness of the particleboard with and without coating

Rhizophora spp. particleboards were prepared into 5.0 × 5.0 × 0.5 cm^3 samples, which were classified into no coating sample, sample coated with gloss finish, sample coated with epoxy resin, and sample coated with both epoxy resin and gloss finish. All samples were conditioned at room temperature (21 °C). No sanding or other finishes were applied prior to and after coating, and no sanding was done before roughness measurements. The coatings were applied three times and left to dry for 24 h. Thirty-two measurements were taken at measurement range of ± 400.00 µm, at measurement length of 4.0 mm with speed of 0.300 mm·s^{-1}. A roughness profilometer (Surfcom 1800G S1400, Accretech, Tokyo Seimitsu, Tokyo, Japan) was calibrated at the calibration value of 0.960057, using a Gaussian type cutoff. Vertical displacement of the stylus is converted into electrical signal by a linear displacement of detector. The signals received were amplified and transferred into digital information (Hiziroglu *et al.* 2004). Standard roughness parameters obtained from the test include average roughness (R_a) and mean peak-to-valley height (R_z), which were calculated from the system.

RESULTS AND DISCUSSION

Linear and Mass Attenuation Coefficients

The energy calibration of the XRF system was carried out using the LEGe detector set up for the measurement of mass attenuation coefficient by recording the mean count rate within a fixed range. The LEGe detector collected the XRF photons emitted from the metal plates, which were niobium (Nb), molybdenum (Mo), palladium (Pd), and tin (Sn). The energy calibration curve of LEGe detector for every peak energy was plotted. The best fit equation obtained was $y = 0.0159x - 0.3109$, giving the conversion factor of 0.0159 keV/channel. The value of coefficient of determination from linear regression, R^2, of the channel-energy calibration curve was 0.9999, indicating excellent linearity between the photon energy and the channel of the XRF system measured by the LEGe detector.

Table 4 shows the energy resolution of LEGe detector at K_{a1} energies of the metal plates. Figure 2 shows the energy calibration of the XRF systems at 16.61 to 25.27 keV K_{s1} photon energy range and Fig. 3 shows the energy resolution calculated. The energy resolution was improved at increasing K_{a1} energies, which was shown by the reduction of FWHM as shown in Table 4.

Table 4. The Energy Resolution of LEGe Detector within the Energy Range of 16.61 keV to 25.27 keV

Peak energy (keV)	Channel Number	FWHM (keV)	Energy Resolution (%)
16.61	1069	29.39	2.7867
17.47	1119	29.46	2.6623
21.17	1357	31.88	2.3744
25.27	1613	35.07	2.1891

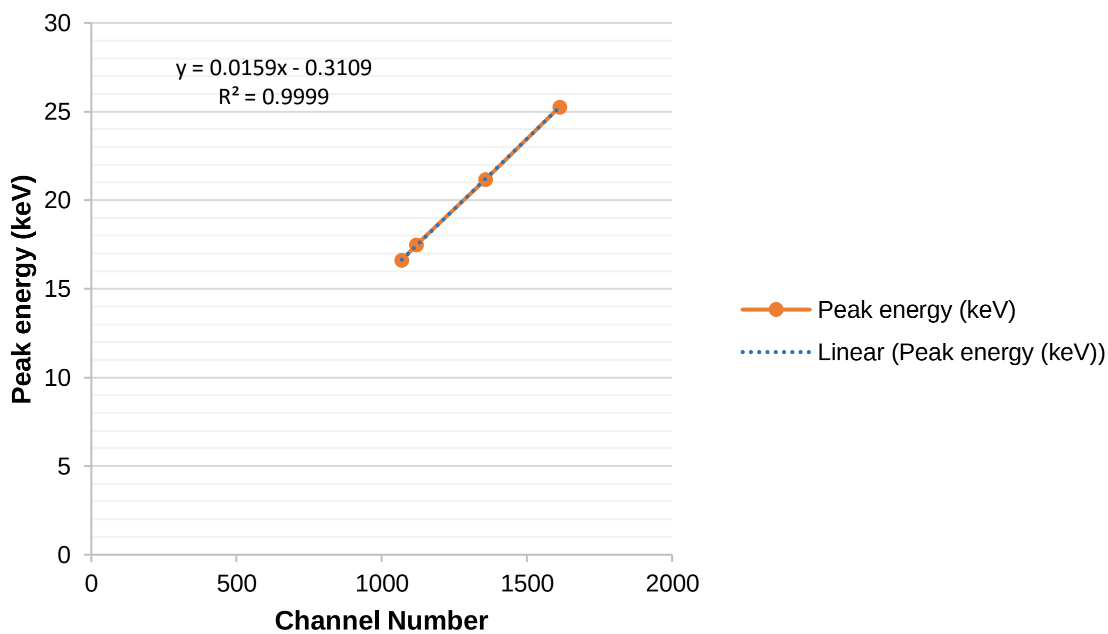

Fig. 2. Energy calibration of XRF at 16.61 keV to 25.27 keV

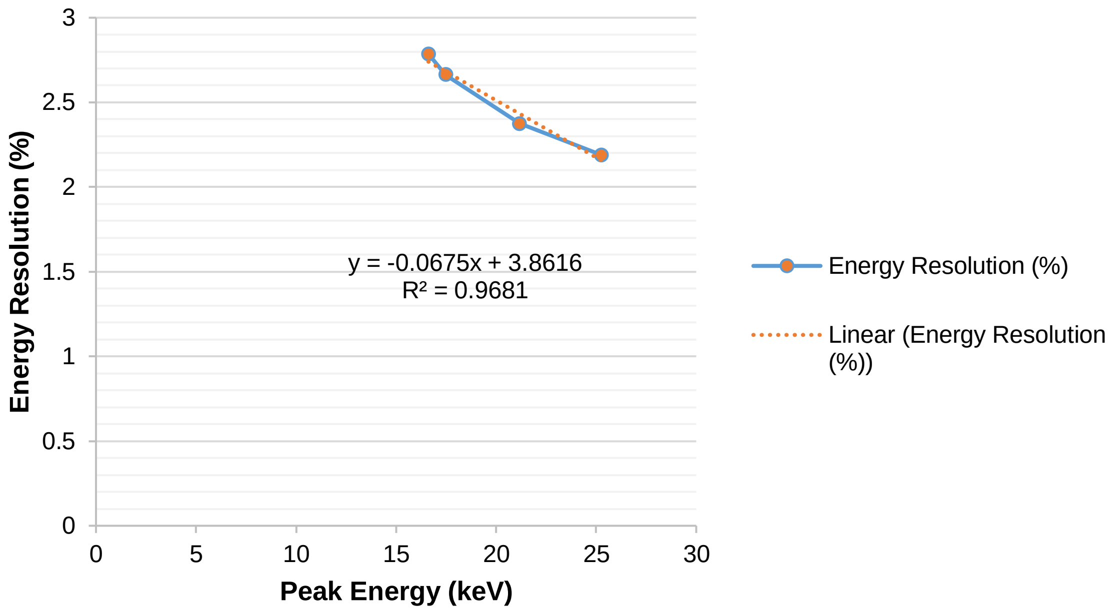

Fig. 3. The energy resolution for LEGe detector calculated

Table 5 shows the linear and mass attenuation coefficients of the fabricated *Rhizophora* spp. particleboard with different percentages of adhesives (6% and 12%) non-coated and coated with gloss finish, epoxy resin, and combination of gloss finish and epoxy resin, at low energy photons in comparison to water (XCOM). The mass attenuation coefficients of the samples are shown in Figs. 4, 5, 6, and 7.

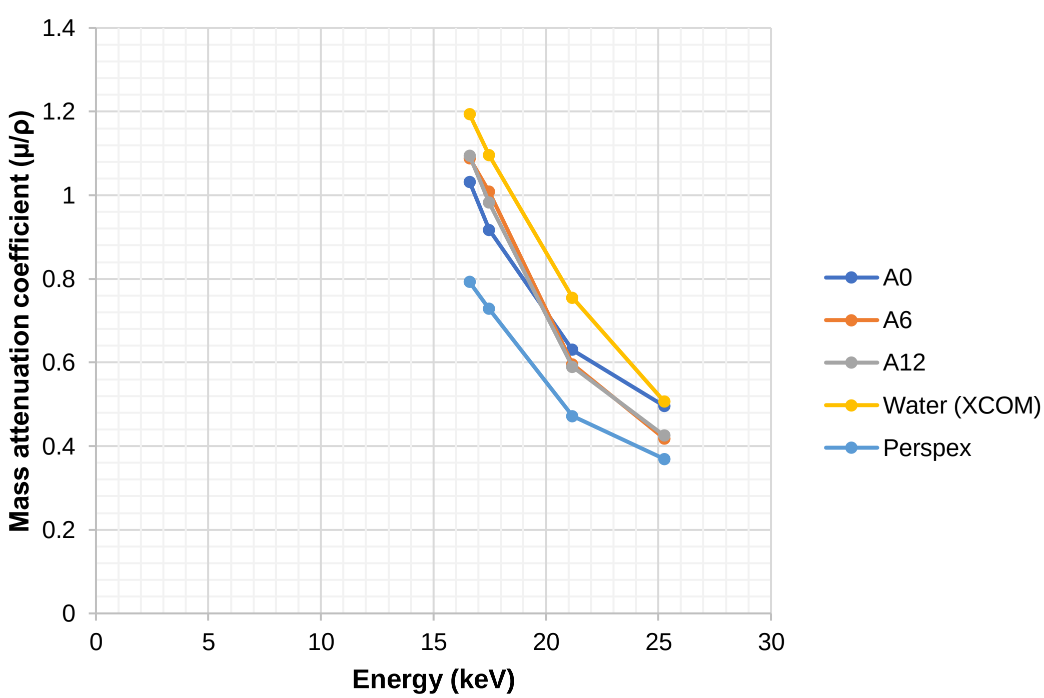

Fig. 4. The mass attenuation coefficients of *Rhizophora* spp. non-coated particleboards in comparison with water (XCOM) and Perspex at energy range of 16.62 to 25.27 keV

Table 5. Linear and Mass Attenuation Coefficients of the Fabricated *Rhizophora* spp. with Low Energy Photons in Comparison to Water (XCOM)

Sample Type	Average Density ($g.cm^{-3}$)	Nb (16.61 keV)			Mo (17.47 keV)			Pd (21.17 keV)			Sn (25.27 keV)		
		μ (cm^{-1})	μ/ρ (cm^2g^{-1})	$\sigma_{\mu/\rho}$	μ (cm^{-1})	μ/ρ (cm^2g^{-1})	$\sigma_{\mu/\rho}$	μ (cm^{-1})	μ/ρ (cm^2g^{-1})	$\sigma_{\mu/\rho}$	μ (cm^{-1})	μ/ρ (cm^2g^{-1})	$\sigma_{\mu/\rho}$
A_6	0.98	1.067	1.088	0.023	0.988	1.008	0.021	0.584	0.596	0.012	0.410	0.418	0.009
A_{12}	0.94	1.028	1.094	0.029	0.924	0.982	0.026	0.554	0.590	0.016	0.399	0.425	0.011
B_6	0.91	0.903	0.988	0.018	0.871	0.953	0.017	0.531	0.581	0.010	0.392	0.428	0.008
B_{12}	0.93	1.053	1.137	0.016	0.937	1.012	0.014	0.520	0.561	0.008	0.410	0.443	0.006
C_6	0.97	0.944	0.971	0.016	0.912	0.938	0.016	0.540	0.556	0.009	0.421	0.433	0.007
C_{12}	0.90	0.877	0.973	0.001	0.893	0.991	0.001	0.538	0.597	0.000	0.410	0.456	0.000
D_6	0.99	1.078	1.094	0.023	1.015	1.029	0.022	0.563	0.571	0.012	0.445	0.468	0.010
D_{12}	0.95	0.997	1.050	0.030	0.968	1.019	0.029	0.542	0.570	0.016	0.421	0.500	0.013
Perspex ®	1.19	0.942	0.792	2.180	0.866	0.728	2.470	0.562	0.472	2.040	0.439	0.369	1.510
Water (XCOM)	1.00	1.193	1.193	-	1.095	1.095	-	0.755	0.755	-	0.506	0.506	-

A = No coating *Rhizophora* spp. sample; B = Sample coated with epoxy resin; C = Sample coated with gloss finish and epoxy resin; D = Sample coated with gloss finish;
0 = 0 % soy flour & lignin, 6 = 4.5 % soy flour & 1.5 % lignin, 12 = 9 % soy flour & 3 % lignin
Particle size used for all samples was 0 – 103 µm

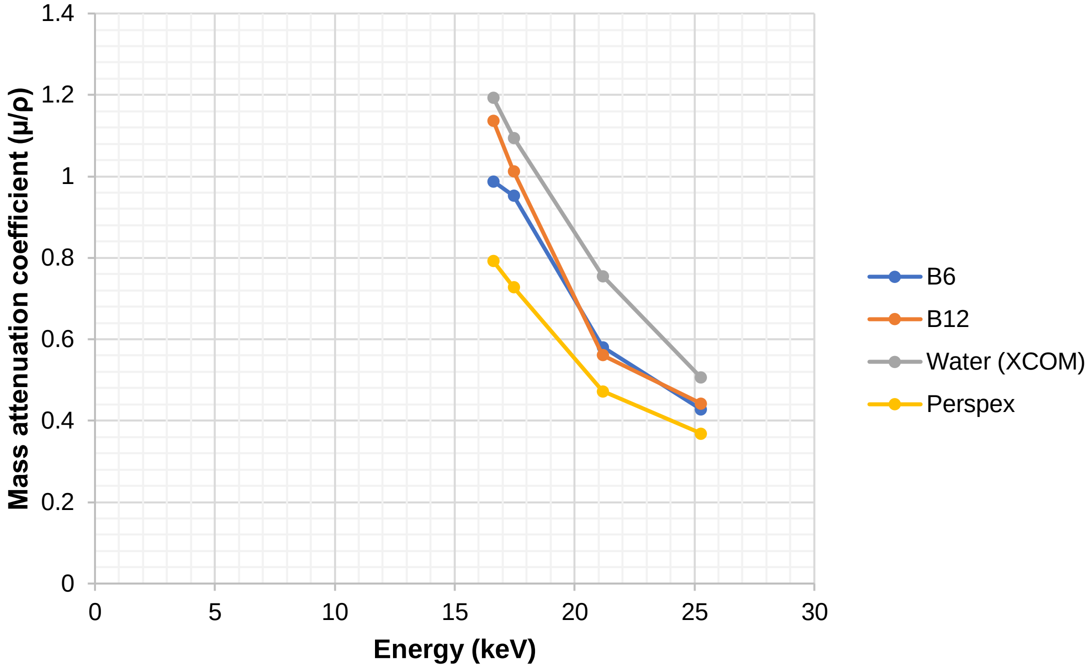

Fig. 5. The mass attenuation coefficients of *Rhizophora* spp. particleboards coated with epoxy resin in comparison with water (XCOM) and Perspex at energy range of 16.62 to 25.27 keV.

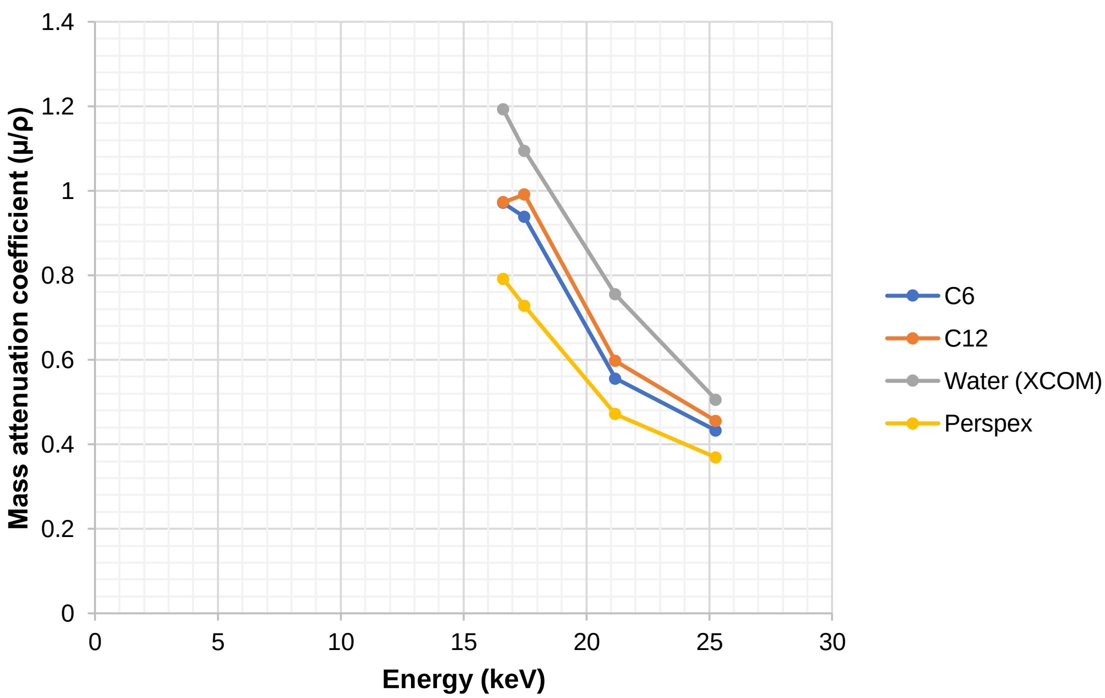

Fig. 6. The mass attenuation coefficients of *Rhizophora* spp. particleboards coated with combination of epoxy resin and glossy finish in comparison with water (XCOM) and Perspex at energy range of 16.62 to 25.27 keV.

Table 6. Paired Sample t-test of the Mass Attenuation Coefficient of the Adhesive-bonded *Rhizophora* spp. With and Without Coating

Sample	Mean Difference	Standard Deviation of Difference	Standard Error of Difference	T Alpha Half 95% CI	Lower Confidence Level	Upper Confidence Level	p-value
A_6 - XCOM	0.10990	0.03397	0.01699	3.182	0.05584	0.16396	0.007
A_{12} - XCOM	0.11460	0.03613	0.01807	3.182	0.05710	0.17210	0.008
B_6 - XCOM	0.14975	0.05441	0.02720	3.182	0.06317	0.23633	0.012
B_{12} - XCOM	0.09915	0.06411	0.03206	3.182	-0.00287	0.20117	0.054
C_6 - XCOM	0.16275	0.06543	0.03272	3.182	0.05863	0.26687	0.016
C_{12} - XCOM	0.13295	0.07260	0.03630	3.182	0.01742	0.24848	0.035
D_6 - XCOM	0.09668	0.06315	0.03158	3.182	-0.00382	0.19717	0.055
D_{12} - XCOM	0.10235	0.07833	0.03916	3.182	-0.02229	0.22699	0.079

A = No coating *Rhizophora spp.* sample; B = Sample coated with epoxy resin; C = Sample coated with gloss finish and epoxy resin; D = Sample coated with gloss finish;
0 = 0 % soy flour & lignin, 6 = 4.5 % soy flour & 1.5 % lignin, 12 = 9 % soy flour & 3 % lignin
Particle size used for all samples was 0 – 103 µm

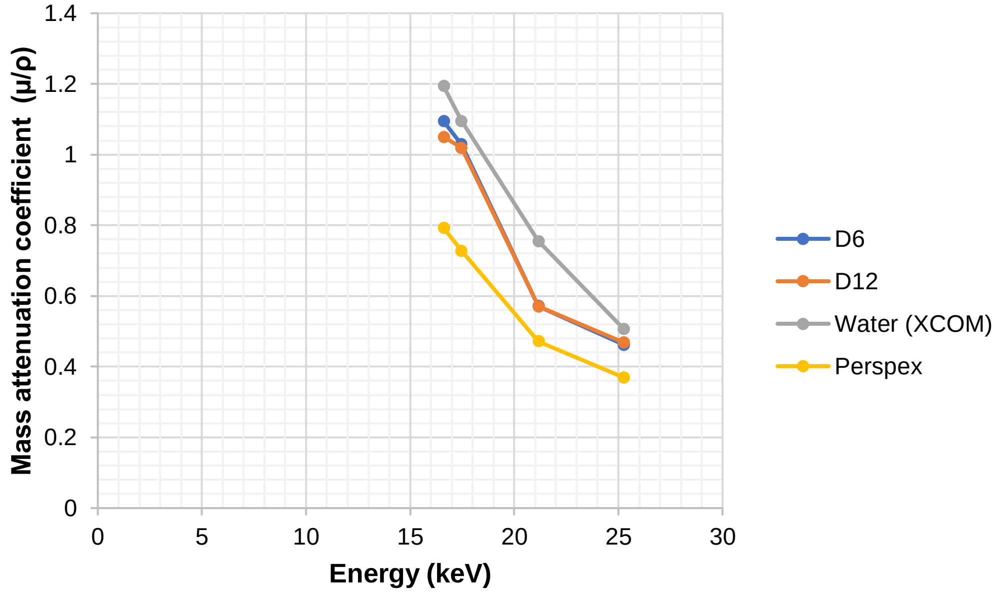

Fig. 7. The mass attenuation coefficients of *Rhizophora* spp. particleboards coated with glossy finish in comparison with water (XCOM) and Perspex at energy range of 16.62 to 25.27 keV.

Table 6 shows the paired sample t-test used to investigate the significant difference between the mass attenuation coefficient of the *Rhizophora* spp. particleboards samples and water from XCOM. The mass attenuation coefficients for samples D_6 and D_{12} (6% and 12% soy-lignin coated with gloss finish) did not have significant difference towards the mass attenuation coefficient of water, with p-value > 0.05. However, the mass attenuation coefficients for other samples differed significantly with p-value less than 0.05 compared with water. This finding revealed the potential of gloss finish as a coating material for wood phantoms. Based on Figs. 4 to 7, the mass attenuation coefficients were close to that of water, which was similar to previous study (Marashdeh *et al.* 2012). This result revealed that the use of coating materials such as gloss finish did not interfere with the attenuation properties of the particleboard, thus confirming the potential of gloss finish as a suitable coating material.

Analysis of Water Absorption and Thickness Swelling

Water absorption and thickness swelling tests for all and coated and non-coated *Rhizophora* spp. particleboard samples are shown in Table 7. Samples D_6 and D_{12} (6% and 12% soy-lignin bonded *Rhizophora* spp. particleboard coated with gloss finish) fulfilled the minimum requirement according to JIS A 5908 (2003) for thickness swelling (12%), whereas the non-coated and other coated sample did not fulfill the minimum condition. Water absorption tests showed that D_6 and D_{12} had relatively low values compared with the others, proving their resistance to moisture. The thickness swelling and water absorption test of the samples were greatly influenced by the coating materials, as similar particle size was used to fabricate all particleboards. The superior result for the sample coated with gloss finish could be due to its properties, which has excellent flow, gloss durability, flexibility, and water resistance in all weather conditions (Aznar *et al.* 2006). The result showed the suitability of gloss finish as potential coating material for the fabrication of tissue-equivalent wood phantom; it allows only a small amount of water absorption compared with the other coating materials.

Table 7. Water Absorption and Thickness Swelling Tests

Sample	TS (%) ± Standard deviation		WA (%) ± Standard deviation	
A_6	29.88	2.46	69.77	3.14
A_{12}	21.83	3.07	50.01	6.58
B_6	14.96	1.55	57.19	1.35
B_{12}	16.75	3.03	55.17	2.62
C_6	14.79	3.25	47.66	1.55
C_{12}	15.01	0.99	55.18	7.86
D_6	12.77	0.49	46.43	0.64
D_{12}	12.39	0.87	51.01	3.05

A = No coating *Rhizophora* spp. sample; B = Sample coated with epoxy resin; C = Sample coated with gloss finish and epoxy resin; D = Sample coated with gloss finish;
0 = 0 % soy flour & lignin, 6 = 4.5 % soy flour & 1.5 % lignin, 12 = 9 % soy flour & 3 % lignin
Particle size used for all samples was 0 – 103 µm

Measurement of the Surface Roughness

The surface roughness results are presented in Table 8.

Table 8. Surface Roughness Measurement

Sample type	Samples	Mass (g)	Density (ρ)	R_a (µm)	Average R_a (µm)	R_z (µm)	Average R_z (µm)
A_6	A	10.06	0.82	5.62	4.37	34.26	26.33
	B	10.15	0.84	6.34		36.71	
	C	10.21	0.84	3.06		17.95	
	D	12.16	0.95	2.47		16.40	
A_{12}	A	9.80	0.80	4.02	5.62	29.17	32.18
	B	9.71	0.79	3.60		22.14	
	C	9.46	0.80	6.05		31.93	
	D	9.41	0.81	8.80		45.48	
B_6	A	12.41	0.96	3.74	3.20	27.01	22.23
	B	12.16	0.95	2.21		17.87	
	C	11.20	0.90	2.83		17.49	
	D	10.87	0.85	4.04		26.55	
B_{12}	A	11.95	0.90	8.10	4.45	47.90	27.57
	B	12.99	0.97	1.82		16.31	
	C	12.23	0.92	2.51		16.95	
	D	10.60	0.91	5.38		29.14	
C_6	A	13.80	1.04	2.69	2.35	18.61	16.88
	B	12.22	1.00	0.89		4.69	
	C	11.29	0.94	2.57		19.17	
	D	10.99	0.92	3.24		25.05	
C_{12}	A	10.20	0.90	3.35	3.58	25.13	24.53
	B	10.12	0.90	3.13		19.35	
	C	9.93	0.90	3.55		25.83	
	D	9.78	0.90	4.28		27.81	
D_6	A	13.03	1.04	1.62	2.01	16.60	15.95
	B	13.23	1.03	1.79		13.19	
	C	11.95	0.95	2.52		18.18	
	D	11.63	0.93	2.09		15.82	
D_{12}	A	12.90	1.00	1.99	1.94	15.55	15.75
	B	12.84	0.99	1.98		15.37	
	C	11.66	0.92	1.30		9.71	
	D	11.45	0.90	2.50		22.37	

The gloss-coated particleboards with 6% and 12% soy-lignin adhesives had the smoothest surface compared with the non-coated, epoxy-coated and gloss-epoxy-coated particleboards, with average R_a of 2.01 µm and 1.94 µm, respectively. Figure 8 shows the typical roughness profile of the gloss-coated *Rhizophora* spp. particleboard.

This finding could be due to the coating material characteristic, which is shiny and mirror-like. The gloss surfaces are exceptionally smooth with only few microscopic irregularities to diffuse or spread light on an angular pattern. The high gloss of the coating is created by successive coats; increasing the number of coatings improves the coating thickness and reduces the surface roughness (Slabejova *et al.* 2016). The raw material used to fabricate particleboard also influences the surface roughness (Nemli *et al*. 2005b). The particleboard with 6% soy-lignin adhesives showed lower surface roughness than particleboard with 12% soy-lignin adhesive for sample type A, B, and C, indicating that a higher amount of *Rhizophora* spp. particles reduce the surface roughness. A higher amount of raw *Rhizophora* spp. particles can be pressed easily during hot pressing with great compression ratio, leading to a tighter and more compact structure (Nemli *et al.* 2005b).

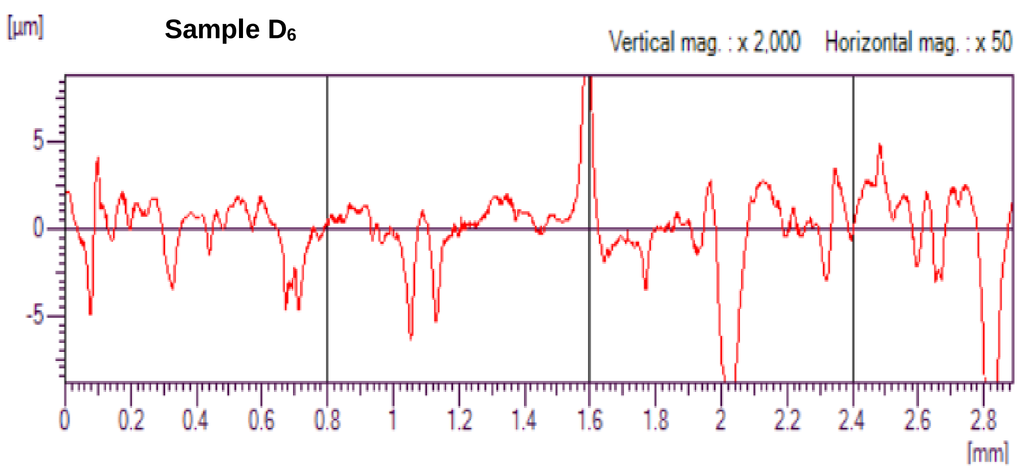

Fig. 8. Roughness profile of gloss-coated *Rhizophora* spp. particleboard for sample D_6 (the linear peak energy is not visible due to device format that only capture predetermined vertical magnification)

CONCLUSIONS

1. Gloss finish can be used as coating for phantom materials made of particleboard for use in medical physics applications.
2. Gloss finish is within the recommended value of 12% according to JIS A 5908 (2003) for water absorption and thickness swelling tests.
3. Surface roughness testing revealed that the sample coated with gloss finish was the smoothest compared with the other coated and non-coated samples.
4. It is essential to account for mass attenuation coefficient of coated phantom material in the validation of its potential in dosimetry application. The mass attenuation coefficient calculated from XRF spectroscopy showed good agreement between the sample coated with gloss finish and water (XCOM).

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