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CHARACTERIZATION OF THE RHIZOPHORA PARTICLEBOARD AS A TISSUE-EQUIVALENT PHANTOM MATERIAL BONDED WITH BIO–BASED ADHESIVE

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ABSTRACT

In this study, some characteristics of *Rhizophora* spp. particleboards bonded with *Serishoom* (traditional animal–based adhesive) as a phantom material was investigated. The *Rhizophora* spp. particleboards were fabricated in two *Serishoom* adhesive treatment levels (6% and 12%) with three *Rhizophora* spp. particle sizes (≤ 149 µm, 149 µm – 500 µm, and 500 µm – 1000 µm) at 1 g.cm^{-3} of the target density. The internal bond strength and the dimensional stability of the *Serishoom*-bonded *Rhizophora* spp. particleboards were improved by using the smaller *Rhizophora* spp. particle size and the higher *Serishoom* adhesive treatment level. The effective atomic numbers of the *Serishoom*-bonded *Rhizophora* spp. particleboards were determineted to be 7,56 to 7,58 by an energy dispersive X-ray, which is in good agreement with those of water and breast tissue. In addition, the density distribution profiles of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards were determined by the *Kriging* method with the use *Surfer8* computer software, which indicated that there was good density homogeneity throughout the *Serishoom*-bonded *Rhizophora* spp. particleboards. The results showed a potential of the *Serishoom*-bonded *Rhizophora* spp. particleboard bonded with *Serishoom* to be used as a phantom material.

Keywords: Bio–adhesive, effective atomic number, particleboard, *Rhizophora* sp., *Serishoo.*

INTRODUCTION

The risks of radiation are always being considered particularly in medical applications. Therefore, a simulated system, which is called phantom, has been used for quality control (QC), quality assurance (QA), and radiation protection (Attix 2008, Khan 2010). The phantom materials should have approximately the same response against radiation with that of human tissue. The interactions of photons with matter depend to some matter properties such as its density and effective atomic number. The water and solid (such as polystyrene and Perspex) homogeneous phantoms have been widely used in medical radiation centers, although they are not always practical and suitable to be used as a phantom (Khan 2010). Furthermore, there is always an interest to use local, readily available, and cheap phantom material, such as wood. Wood (with similar density of water as a standard material phantom) has been considered as a phantom material for some unique properties such as renewable, biodegradable, low toxicity, readily available, cheap, and easy to use and prepare (Tousi *et al.* 2014b).

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Rhizophora spp. is traditionally being used to produce charcoal and as building materials (Atheull *et al.* 2009, Abuarra *et al.* 2014). It is a significant genus of mangrove trees that grows in the salty littoral tropical and subtropical sedimentary habitats (Hogarth and Hogarth 2007). The *Rhizophora* has the various genuses, and *Rhizophora* spp. refers to all types of the *Rhizophora* trees. Since the proposition of the suitability of *Rhizophora* spp. wood as a phantom material in 1988 (Sudin *et al.* 1988), some researchers have been investigating its characteristics further (Bradley *et al.* 1991, Tajuddin *et al.* 1996, Munem 1999, Banjade *et al.* 2001, Shakhreet *et al.* 2009). Nevertheless, there are some limitations for the utilization of the raw wood as a phantom, such as, the uncontrollable uniformity of some significant characteristics such as moisture content and density throughout the raw wood phantom. Furthermore, the raw wood tends to grow mold, get slimy, cracks and warps all over the wood phantom with passing time (Marashdeh *et al.* 2011). In addition, the *Rhizophora* spp. tree trunk is typically 20 cm to 25 cm in diameter (Hogarth and Hogarth 2007) and is not suitable to be used as a standard phantom with a typical size of 30 cm × 30 cm × 30 cm.

The woods can be used in two general forms: raw wood, and engineered wood–based panels such as particleboard. *Rhizophora* spp. particleboard phantom has been considered by some researchers as an alternative to the raw wood phantom. The particleboards can be classified into two general types: binderless, and with the use of a binder material.

In a binderless particleboard, the wood particles bind together with some treatment such as pressure and temperature, in the absence of an adhesive. Marashdeh *et al.* 2011 investigated the properties of Rhizophora spp. binderless particleboard (Marashdeh *et al.* 2011, Marashdeh *et al.* 2012). The results of the mass attenuation coefficients were found very close to water as the standard material phantom (Marashdeh *et al.* 2012). However, the low internal bond (IB) strength of the Rhizophora spp. binderless particleboard restricts the practical utilization in medical radiation centers (Marashdeh *et al.* 2011). This is due to the fact that the binderless *Rhizophora* spp. particles were easily disintegrated by water in a short time. Thus, the dimensions of *Rhizophora* spp. binderless particleboards were not stable in the determination of water absorption (WA) and thickness swelling (TS).

The use of an adhesive as the binder in the *Rhizophora* spp. particleboard had also been considered. The adhesives can be classified into two main groups: synthetic and bio–based wood adhesives. The synthetic adhesives included urea formaldehyde (UF), phenol formaldehyde (PF) and phenol resorcinol formaldehyde (PRF), as the most widely used adhesives in the wood industry (Chew *et al.* 1991, MacDonald 2013), were used to fabricate *Rhizophora* spp. particleboards (Surani 2008, Ngu 2009). The mass attenuation coefficients of the *Rhizophora* spp. particleboard with UF, PF, and PRF synthetic wood adhesives were significantly far from those of breast tissue and water at 59,5 keV photon energy. Moreover, thermal resistance of the formaldehyde is very low, that causes the emission of formaldehyde fume with passing time from formaldehyde–based wood adhesives (Hashim *et al.* 2011). The International Agency for Research on Cancer (IARC) has recognized formaldehyde as a carcinogenic substance (Bosetti *et al.* 2008). Therefore, formaldehyde–based wood adhesives can potentially be harmful for environmental and human (Hashim *et al.* 2009, Moubarik *et al.* 2010).

Natural adhesives have been used since the ancient civilizations such as in Iran, China, and Egypt (Bianchini and Meli 2002, Liu and Li 2002). There is always a concern about famine food in the world about the widely increasing utilization of bio–based materials in the fuel and industries. In this study, a type of animal-based adhesive was used to fabricate the *Rhizophora* spp. particleboards with 1 $g.cm^{-3}$ target density. This animal–based adhesive has been traditionally used and named *Serishoom* in Iran (Tousi *et al.* 2014c). *Serishoom* has been made from the inedible connective tissues (such as cartilage and bone) of domesticated ungulate animals (especially cow and goat) by prolonged boiling process. The dried *Serishoom* consists 85,7% crude protein, 13,7% ash (mineral materials), and less than 1% total of the fat, fiber, and carbohydrate (Tousi *et al.* 2014c). Therefore, *Serishoom* can be classified as a protein–based adhesive. The viscosity of the Serishoom was about 6 – 25 mPa.s, which was in the viscosity range of the widely used synthetic adhesives in wood industry such as urea-formaldehyde (UF) and phenol-formaldehyde (PF) (Tousi *et al.* 2014a). Also, the viscosity of less than 50 mPa.s makes easier handling of the *Serishoom*.

In this study, *Rhizophora* spp. particleboards were fabricated using three *Rhizophora* spp. particle sizes (≤ 149 µm, 149 µm – 500 µm, and 500 µm – 1000 µm), and two *Serishoom* adhesive treatment levels (6% and 12%). The internal bond (IB) strength, water absorption (WA), and thickness swelling (TS) were evaluated as the mechanical and physical properties of the fabricated *Rhizophora* spp. particleboards. Also, the elemental composition and the effective atomic numbers of the *Serishoom* adhesive and the fabricated *Rhizophora* spp. particleboards were investigated with an energy dispersive X-ray (EDX). In addition, the density distribution profiles of the fabricated *Rhizophora* spp. particleboards were determined by the *Kriging* method with the use *Surfer8* computer software.

MATERIALS AND METHODS

Preparation of Samples

Rhizophora ssp. tree trunks, which were directly collected from the mangrove forestry office in Kuala Sepetang, Perak, Malaysia, were peeled and sawn into planks with approximately same thickness by a Formahero FH-600 BS saw. Then, the wood planks were repeatedly passed through an auto planer (Holy Tek HP 20) for shaving. The shavings were air dried and later ground to produce very small particles by a Tai–Yi Retch grinder. Finally, the *Rhizophora* spp. particles were screened by a horizontal screening machine to three different *Rhizophora* spp. particle sizes: ≤ 149 µm, 149 – 500 µm, and 500 – 1000 µm.

The *Serishoom* was directly purchased from the traditional adhesive market in Mashhad, Razavi Khorasan Province, Iran. The *Serishoom* was ground and screened in sieves of 149 µm – 500 µm particle size. The density of a water–equivalent phantom should be 1 g.cm^{-3}, so the target density of the fabricated particleboards was set at 1 g.cm^{-3}. The moisture content (MC) of the *Serishoom* and *Rhizophora* spp. particles were measured based on the Japanese Industrial Standard (JIS 2003) by using a Radwag MAC 50/1 digital moisture analyzer. The MC is affected by some properties in the surrounding area such as humidity and temperature. Therefore, MC was measured before each step. The MC values of the *Rhizophora* spp. and *Serishoom* particles were typically determined to be 6–8% and 4–6%, respectively. *Serishoom* makes the stronger binding with additional water similar to other bio–based adhesive powder. The *Rhizophora* spp. particleboards bonded with *Serishoom* were fabricated with 10% to 40% of the amount of the additional water. The binders were easily fractured in the fabricated *Rhizophora* spp. particleboard with low percentage of the additional water. In other hand, the cleft surface was appeared in a high percentage of added water. As well as, with more additional water longer time is needed to remove moisture from the particleboard in the fabrication process, which causes the fabricated particleboard to be burnt. The 20% water in general (including the moisture contents of wood and glue particles) was used for stronger bonding in particleboard fabrication. The calculation for the particleboard fabrication is shown in Equation 1 (Tousi *et al.* 2014b):

$$\begin{aligned} &\rho = \frac{M}{V}; \rho_t = 1g.cm^{-3} \\ &M_w = (\%W) \times \rho V(1 + \%MC_w); M_{Seri} = (\%Seri) \times \rho V(1 + \%MC_{Seri}) \\ &M_{water} = (20\%) \times \rho V - \left[(M_w \times \%MC_w) + (M_{Seri} \times \%MC_{Seri})\right] \end{aligned} \quad (1)$$

where ρ, ρ_t, *M,* and *V* are the density, target density, mass, and volume of the fabricated particleboard, respectively. M_w, *%W* and $\%MC_w$ are the mass, weight percentage, and moisture content of *Rhizophora* spp. wood particles, respectively. In addition, M_{Seri}, *%Seri* and $\%MC_{Seri}$ are the mass, weight percentage, and moisture content of the Serishoom adhesive, respectively. M_{water} is the mass of the additional water needed. The *Rhizophora* spp. particleboards bonded with *Serishoom* were fabricated in 21 cm × 21 cm × 0,65 cm board size, approximately. In total 18 particleboards were fabricated, three particleboards for each of the 6 types. Table 1 shows the measured density of the *Rhizophora* spp. particleboard samples with three *Rhizophora* spp. particle sizes bonded with *Serishoom* at two adhesive treatment levels.

Table 1. Samples of the *Rhizophora* spp. particleboards with three *Rhizophora* spp. particle size, bonded with two weight percentages of the *Serishoom* adhesive.

Sample	Seri. %	Rhiz.P.S. µm	Density (g.cm^{-3}) Max	Min	Avr.	St.Dv.
A	6	500-1000	1,02	0,98	1,01	0,05
B	12	500-1000	1,05	0,94	1,01	0,01
C	6	149-500	1,01	0,99	1,01	0,01
D	12	149-500	1,09	0,99	1,06	0,01
E	6	<149	1,08	0,96	1,03	0,02
F	12	<149	1,08	0,91	1,01	0,01

Seri. %: % Weight *Serishoom*; St.Dv.: Standard Deviation
Rhiz. P.S.: Particle Size *Rhizophora* spp.; Avr.: Average

The fabrication process included two parts. The first part was cold pressing for about 15 min at 20 MPa pressure. The second part was hot pressing that included four sections: (1) 10 MPa pressure for 10 min in the rising temperature from 29 °C (room temperature) to 100 °C; (2) 13 MPa pressure for 10 min in the increasing temperature from 100 °C to 150 °C; (3) 16 MPa pressure for 10 min in enhancing temperature from 150 °C to 200 °C. (4) 20 MPa pressure for 5 min in the fixed temperature of the adhesive melting point. The particleboards were intermittently put under the pressure to gradually remove the water steam from the particleboard in order to avoid cracks on the fabricated particleboards.

Internal Bond (IB) strength

The fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards, were cut into 5 cm × 5 cm of samples to evaluate the internal bond (IB) strength based on the Japanese Industrial Standard for particleboard (JIS 2003). The samples were stuck to the aluminum IB moulds in 5 cm × 5 cm surface size (sample and aluminum IB moulds have to be in the same sizes) from both sides by a hot–melt glue. The IB strength values were evaluated five times for each sample type. An UTM-5582: Instron Testing System (USA) with a load cell capacity of 1000 kg was used to determine the IB strength of the fabricated *Rhizophora* spp. particleboards bonded with *Serishoom*. The samples were pulled apart from both sides until the appearance of the fracture, which have to occur in the middle of the sample. The IB tester system gave a curve for each sample that showed the maximum load at the fracture time (P_{max}). The IB strength value is calculated by Equation 2:

$$IB\ (MPa) = P_{max} / (\text{Area of the board sample surface}) \tag{2}$$

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Water Absorption (WA) and Thickness Swelling (TS)

The practical utilization of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboard can be significantly affected by its dimensional stability, which can be evaluated by the WA and TS analyses. The fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards were cut into 3 cm × 3 cm board samples. The WA and TS of 6 samples from each of the 6 different types of fabricated particleboards were measured. According to the Japanese Industrial Standard for particleboards (JIS, 2003), the samples were immersed in distilled water at room temperature for 24 hours (Sahin and Arslan 2011). The thickness and the weight of the samples were measured in before immersion in water and after 30 min, 1, 2, 4, 6, 9, 12, 15, and 24 hr of the immersion time. The WA and TS were calculated by Equations 3 and 4, respectively (JIS 2003):

$$WA\% = \left(\frac{W - W_0}{W_0}\right) \times 100 \tag{3}$$

$$TS\% = \left(\frac{T - T_0}{T_0}\right) \times 100 \tag{4}$$

where W_0 and T_0 are the initial weight and thickness of the samples, respectively. Also, W and T refer to the weight and thickness of the samples after 24 h of immersion time, respectively.

Density Distribution

The density distributions of the fabricated *Rhizophora* spp. particleboards bonded with the *Serishoom* adhesive were determined by the *Kriging* method with the use *Surfer8* computer software. The "Optimal prediction" is the literal meaning of the *kriging* (Journel and Huijbregts, 2003). The *Kriging* method derives the required parameter values at an unobserved location with random real measured data. The *Rhizophora* spp. particleboards bonded with *Serishoom* were fabricated in 21 cm × 21 cm × 0,65 cm. The edges of fabricated particleboards were cut about 0,5 cm by a Formahero FH-600 BS saw. Then, 100 board samples of 2 cm × 2 cm size were obtained from each fabricated *Serishoom*-bonded *Rhizophora* spp. particleboard by cutting. The density of each board sample was measured with an MD–200S, Alfa Mirage (Japan) electronic densimeter in g/cm^3 with 0,001 g.cm^{-3} accuracy. As well as, the dimensions of the cut board samples were measured by using a digital vernier callipers in cm with 0,001 cm accuracy. *Surfer8* computer software is widely used to simulate a grid-based map from relation of 3 parameters (XYZ file) to find the equivalence points based on random real data XYZ input file (Golden-Software 2002). The locations coordinate of the middle point of each board samples were loaded as X and Y files (based on the measured dimensions). Z was the measured density of each board sample.

Evaluation of the elemental composition and the effective atomic number

The photoelectric effect, which is one of the most significant interaction of photons with matter especially in the low-energy photon range such as in a mammography technique, is actively affected by the atomic number (Z) of the element or the effective atomic number (Z_{eff}) of the composite materials (Gunderson and Tepper 2007, Attix 2008, Olarinoye 2011). Hence, the response of two materials with the same effective atomic number could be significantly closer together under the radiation especially in the low-energy range. The effective atomic number of the new phantom material has to be in good agreement with those of human tissue and water as the standard phantom material. The Zeff is calculated by Equation 5 (Tsai and Cho 1976, Duvauchelle *et al.* 1999, Olarinoye 2011):

$$Z_{eff} = \left(\sum_{i=1}^{N}\left(\alpha_i Z_i^m\right)\right)^{\left(\frac{1}{m}\right)} \tag{5}$$

where α_i and Z_i are the electronic fraction and atomic number of the i^{th} element in the composite, respectively. Also, m is an experimental coefficient, which is 3,4 for the biological substance such as tissue and wood (Tsai and Cho 1976, Duvauchelle *et al.* 1999). As well as, using Equation 6 gives the electronic fraction of the i^{th} element (αi) (Duvauchelle *et al.* 1999, Olarinoye 2011):

$$\alpha_i = \frac{w_i\left(\frac{Z_i}{A_i}\right)}{\sum w_i\left(\frac{Z_i}{A_i}\right)} \tag{6}$$

where, w_i, Z_i, and A_i are fractional weight, atomic number, and atomic number of the i^{th} element, respectively. An energy dispersive X-ray (EDX) (model: Oxford X-ray Act) was used to evaluate the elemental compositions of the *Serishoom* adhesive and the fabricated *Rhizophora* spp. particleboards with three *Rhizophora* spp. particle sizes bonded with *Serishoom* in two treatment levels in three replicates for the different samples. All elements of the Periodic Table can be detected by EDX technique, except hydrogen and helium (Neagle and Randell 1990).

RESULTS AND DISCUSSION

Characterization of the internal bond strength

Figure 1 shows the average of the IB strength values of *Rhizophora* spp. particleboard bonded with *Serishoom*. The minimum requirement for the IB strength value for types 8, 13, and 18 particleboards are 0,15, 0,20, and 0,30 MPa respectively by the Japanese Industrial Standard for particleboards JIS, A–5908 (JIS 2003).

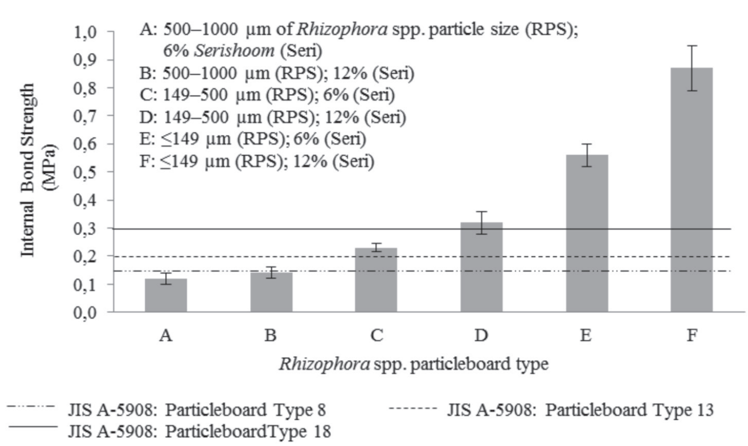


Figure 1. Internal Bond (IB) strength values of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards.

The IB strengths of Samples A and B with the biggest *Rhizophora* spp. particles (500 – 1000 μm) could not meet the required minimum IB strength values of the Japanese Industrial Standard for particleboards JIS, A–5908 (JIS, 2003). The IB value of Sample C was found higher than the minimum IB strength values of types 8 and 13 particleboards by the Japanese Industrial Standard for particleboards JIS, A–5908. Samples D, E, and F covered the minimum IB strength values of types 8, 13, and 18 particleboards by the Japanese Industrial Standard for particleboards JIS, A–5908. Thus, the IB strength of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboard bonded with *Serishoom* is affected by the *Rhizophora* spp. particle size and adhesive treatment level.

Geometrically, the *Rhizophora* spp. particles with smaller size have less void space and more connecting surface areas to hold together. The increase in the connecting surface area causes the increase in the IB strength value (Hashim *et al.* 2010). Hence, the IB strength value of the fabricated *Rhizophora* spp. particleboard increased with the smaller *Rhizophora* spp. particle sizes, as in the studies of the *Rhizophora* spp. (Marashdeh *et al.* 2011), oil palm (Hashim *et al.* 2010), aspen bark (Yemele *et al.* 2008), and rice husk (Osarenmwinda and Nwachukwu 2007) binderless particleboards. The IB strength value of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboard also increased with higher *Serishoom* adhesive treatment level due to the presence of more binding *Serishoom* adhesive particles.

Evaluation of the water absorption and thickness swelling

Figures 2 and 3 show the WA and TS values of the fabricated *Rhizophora* spp. particleborads bonded with *Serishoom* adhesive.

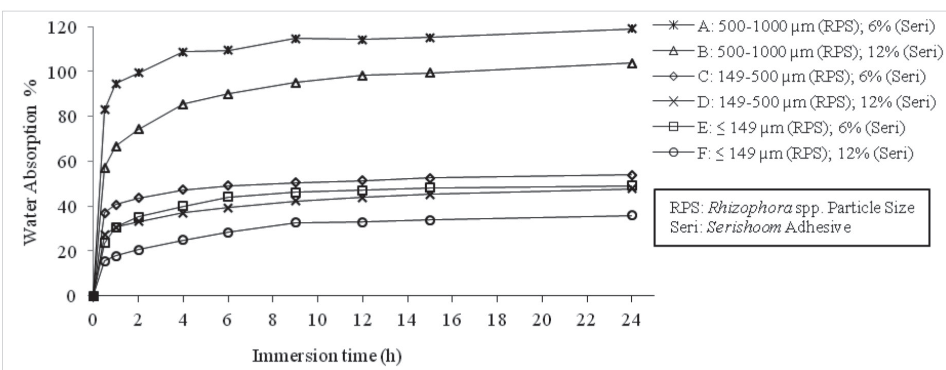


Figure 2. The percentage of water absorptions of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards.

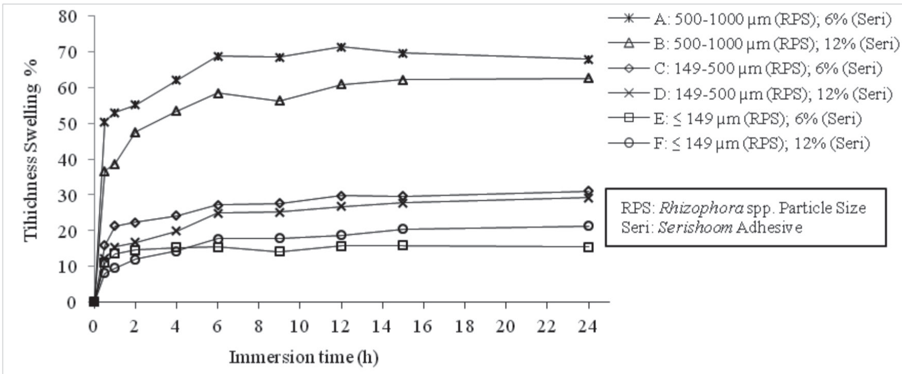
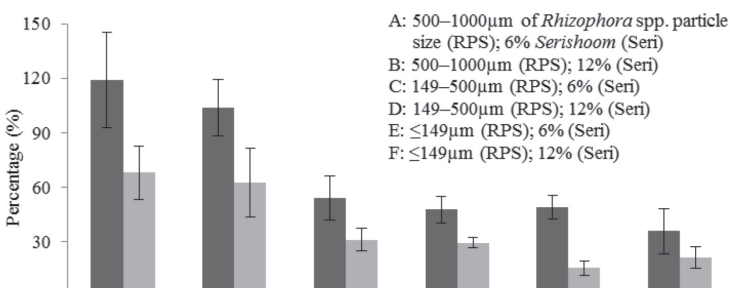


Figure 3. The percentage of thickness swelling of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards.

The WA and TS values of all samples quickly increased in the first 30 min after the start of immersion process. The WA and TS values of the fabricated *Rhizophora* spp. particleboards slowly increased after the first hour of the immersion time. The WA and TS values of the fabricated particleboard represent the dimensional stability. The lower WA and TS values indicate the more dimensional stability of the particleboard (Nadhari *et al.* 2013, Tousi *et al.* 2014b). Figure 4 shows the WA and TS values of the fabricated *Rhizophora* spp. particleboards after 24 h of the immersion time.



	A	B	C	D	E	F
WA	119,08	103,63	53,94	47,64	48,98	35,86
TS	68,01	62,67	31,08	29,24	15,43	21,33

Figure 4. The WA and TS values of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards after 24 hours immersion time.

According to figure 4, the absorption of water is significantly affected by the types of samples. The WA and TS values of the fabricated *Rhizophora* spp. particleboards at the same adhesive treatment level (6%: Sample A, C, and E; 12%: Samples B, D, and F) increased with the increase of *Rhizophora* spp. particle size. The smaller dimension of the *Rhizophora* spp. particles makes the smaller void space. Therefore, the connecting area increases with smaller *Rhizophora* spp. particle. The dimensional stability increases with more connecting area.

The WA and TS values of the fabricated *Rhizophora* spp. particleboard decreased with the increase of *Serishoom* adhesive treatment level for the same *Rhizophora* spp. particle size (500 µm – 1000 µm: Samples A and B; 149 µm – 500 µm: Samples C and D; ≤ 149 µm: Samples E and F), except the TS value at ≤ 149 µm of the *Rhizophora* spp. particle size (Samples E and F). The more adhesive particles cause to make the stronger binding in throughout of the fabricated *Rhizophora* spp. particleboard. The *Serishoom* particle size was 149 µm – 500 µm for all samples. Therefore the hydrophilic bigger *Serishoom* adhesive particles absorbed more water in the fabricated *Rhizophora* spp. particleboard with smallest *Rhizophora* spp. particle (≤ 149 µm: Samples E and F). In general, the dimensional stability of the fabricated *Rhizophora* spp. particleboard increased with higher *Serishoom* adhesive treatment level.

Density distribution profile

The contour lines of equal density of the fabricated *Rhizophora* spp. particleboards bonded with *Serishoom* adhesive were simulated with the *Kriging* method by *Surfer8* computer code, which are shown in figure 5. The lowest density value was related to the edge areas of the fabricated *Rhizophora* spp. particleboards, where the moisture in the particleboard escaped as steam from the particleboards during the hot pressing. The density of the edges shows the most deviation from the 1 g.cm^{-3} target density.

Table 2 shows the maximum, minimum, mean, and the percentage difference from target density (1 g.cm-3) for the fabricated Rhizophora spp. particleboards bonded with Serishoom. The difference between the density values of the fabricated Rhizophora spp. particleboards and target material (water) were found to be less than 5%.

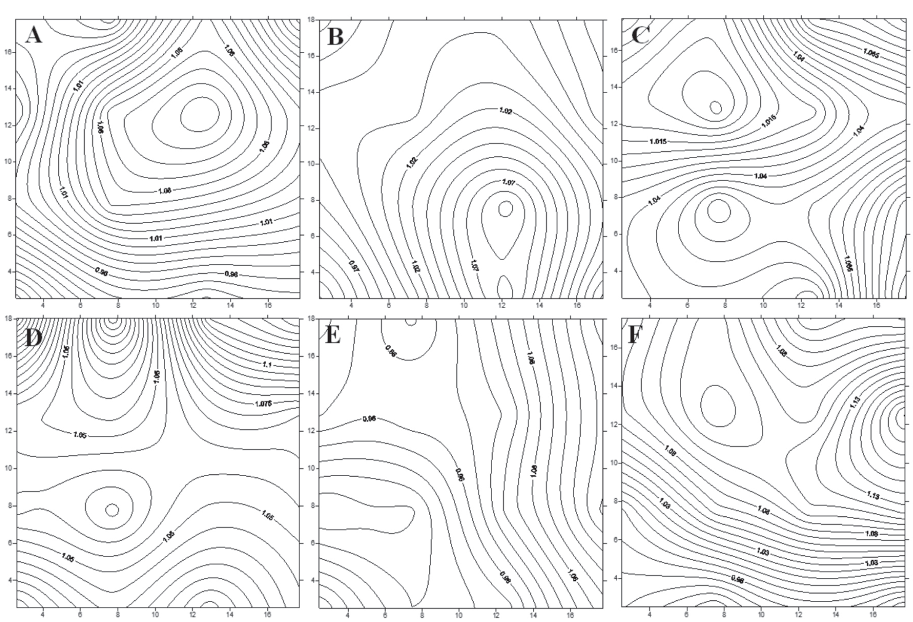


Figure 5. The simulated contour lines of equal density of *Serishoom*-bonded *Rhizophora* spp. particleboards by using the *Surfer8* computer software.

Table 2. The results of the simulated density values of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboard using the *Kriging* method by *Surfer8* computer software.

Sample	Density ($g.cm^{-3}$)			Difference with target density (%)	St. Dv.
	Min	Max	Mean		
A	0,90	1,10	1,01	1,20	0,06
B	0,95	1,09	1,01	1,16	0,03
C	1,00	1,08	1,02	2,08	0,03
D	1,00	1,14	1,05	4,06	0,03
E	0,92	1,06	0,98	2,20	0,04
F	0,92	1,19	1,04	4,20	0,08

St.Dv.: Standard Deviation

Therefore, all of the fabricated *Rhizophora* spp. particleboards were found close to the target density. Sample F (with the smallest *Rhizophora* spp. particle size and the higher *Serishoom* adhesive treatment level) has the biggest standard deviation value, which indicates the lowest density homogeneity of the *Serishoom*-bonded *Rhizophora* spp. particleboards. Also, the density of the fabricated *Rhizophora* spp. particleboard was further from the target density by the increased *Serishoom* treatment level with the same *Rhizophora* spp. particle size, exept the *Serishoom-Rhizophora* spp. particleboards with the biggest *Rhuzophora* paricles (Samples A and B). As well as, the density of the fabricated *Rhizophora* spp. particleboard was closer than target density by the increased *Rhizophor*a spp. particle size for the same *Serishoom* treatment level.

Evaluation of the effective atomic number

Table 3 shows the elemental components and the measured effective atomic number of *Rhizophora* spp. wood (Sudin, 1993), water (AAPM-21 1983, AAPM-25 1988, Qi *et al.* 2010), young–age breast tissue (25% fat and 75% muscle) (Shakhreet *et al.* 2009), *Serishoom* adhesive, and fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards. The Z_{eff} of the *Serishoom* adhesive and the *Rhizophora* spp. wood was calculated 8,48 and 7,31, respectively. Therefore, Z_{eff} value of the *Rhizophora* spp. wood was found very close to those of water and young–age breast tissue, with 1,48% and 0,27% of the percentage difference, respectively. Nevertheless, the Z_{eff} of Serishoom adhesive was not in good agreement with those of water and young–age breast tissue. Therefore, the *Serishoom* can not be used alone as a phantom material.

Table 3. The elemental components and the calculated effective atomic number of water, breast tissue (young–age), *Rhizophora* spp. wood, *Serishoom* bio–adhesive, and fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards.

Sample	Elemental Components											Z_{eff}
	H	C	N	O	Na	Mg	P	S	Cl	K	Ca	
Water [a]	11,11			88,89								7,42[d]
Breast 1[b]	10,70	28,30	2,63	57,60	0,06	0,02	0,15	0,38	0,06	0,23	0,01	7,29
Rhiz. [c]	5,41	40,20	0,03	54,40								7,31
Seri.		40,80	26,20	26,50	2,21	0,14	0,44		2,96		0,65	8,48
A		27,25		72,75								7,57
B		27,05		72,95								7,58
C		27,32		72,68								7,57
D		27,26		72,74								7,57
E		27,33		72,67								7,57
F		28,15		71,85								7,56

[a]: (AAPM-21 1983); [b]: (Shakhreet *et al.* 2009); [c]: (Sudin 1993); [d]:(Constantinou 1982); Breast 1: Young–Age Breast Tissue (25% fat and 75% muscle); Rhiz.: *Rhizophora* spp. raw wood; Seri.: *Serishoom* adhesive.

Carbon and oxygen were only detected as the component elements in all fabricated *Rhizophora* spp. particleboards bonded with *Serishoom* adhesive. The Z_{eff} values of the fabricated *Rhizophora* spp. particleboards were calculated to be in the range of 7,56 to 7,58. Therefore, the percentage errors of the Z_{eff} values of the fabricated *Rhizophora* spp. particleboards with young age breast tissue were found to be 3,70% to 3,98%. As well as, the percentage of the difference between Z_{eff} of the fabricated *Rhizophora* spp. particleboards and that of water were 1,89% to 2,16%. Therefore, the Z_{eff} values of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards were found very close to those of water and breast tissue, which indicates its potential to be used as a phantom material.

CONCLUSIONS

In this study, the characteristics of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards in two adhesive treatment levels (6% and 12%) and three *Rhizophora* spp. particle sizes (≤ 149 µm, 149 – 500 µm, and 500 – 1000 µm) with 1 g.cm^{-3} target density were investigated. Their internal bond (IB) strength, water absorption (WA), and thickness swelling (TS) were evaluated. The IB strength value increased with the smaller *Rhizophora* spp. particle size and higher *Serishoom* treatment level. Also, the WA value decreased with the reduced *Rhizophora* spp. particle size and increased *Serishoom* adhesive treatment level. Similarly, the TS value decreased with the smaller *Rhizophora* spp. particle size. The TS value, however, increased with the higher *Serishoom* adhesive treatment level for ≤ 149 µm of the *Rhizophora* spp. particle size, which showed the hydrophilic property of the *Serishoom* adhesive. The effective atomic numbers (Z_{eff}) of the fabricated *Serishoom*-bonded *Rhizophora* spp. particleboards were found very close to those of water and young–breast tissue, which shows its potential as a phantom material. In addition, the density distribution profiles of the fabricated *Rhizophora* spp. particleboards (with 1 g.cm^{-3} target density) were determined by the *Kriging* method with the use *Surfer8* computer software indicates the potential of the *Serishoom*-bonded *Rhizophora* spp. particleboard as a phantom material especially in diagnostic photon energy level.

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