Microstructure Examination, Elemental Composition Analysis of Gum Arabic Bonded *Rhizophora* Spp. Particleboards and Their Potential as Tissue Equivalent Material

Ali. Abuarra, Sabar Bauk, Rokiah Hashim, Sivamany Kandaiya, Ehsan Taghizadeh Tousi, and Khalid Aldroobi

***Abstract*—**Never before, gum Arabic (GA) has been used as a bio-adhesive in particleboard manufacturing. For the first time, GA is used in this study as a binder in *Rhizophora* spp. particleboards. The fabricated particleboards were evaluated in terms of field emission scanning electron microscopic (FESEM) surface features and carbon, hydrogen, nitrogen, and sulfur (CHNS) elemental composition to study their potential as tissue equivalent substitute. The FESEM showed the gum Arabic distributing homogeneously within the cells either coating or filling up in between compressed fibres. No spaces were found in the GA bonded particleboards which justifies the macroscopic smooth surface as seen by naked eyes. Furthermore, the CHNS analysis revealed that *Rhizophora* spp partcicleboards have all the required major elements found normally in tissues and in closely comparable amounts to those in tissues. *Rhizophora* spp particleboard samples have the potential to be good representatives of human tissues and more specifically human breast tissue.

***Keywords*—**Elemental composition, FESEM, gum Arabic, *Rhizophora* spp.

I. Introduction

TISSUE equivalent materials are widely used in routine quality assurance and quality control of diagnostic and therapeutic physics. A material is regarded equivalent to a real tissue if it possesses the same radiation characteristics within the relevant energy range in addition to similar physical and chemical properties such as mass density, electron density and elemental composition. Currently, there are several commercially available tissue equivalent materials which offer simple, convenient and accurate simulations for therapy dose determinations in electron and photon applications. However, currently available tissue equivalent materials may not be very accurate in the determination of the calibration curves because of their limitation in mimicking radiation characteristics of the corresponding real tissues in both low and high energy ranges encountered in diagnostic radiology [1]. Therefore, it is necessary to look for new materials with tissue equivalent properties for the calibration purposes.

The mangrove *Rhizophora* spp. wood was reported to have attenuation properties that match with water and breast tissue, but, it was found that particleboards are better than the raw wood. Hence, grinding the raw wood into small particles and compressing them into particleboards will improve the attenuation properties, allow the addition of other extra substances that enhance the physical and mechanical properties of the particleboards and will facilitate the fabrication of tissue equivalent phantoms in the desired shape, density and size.

Nowadays, most of the commercially available particleboard adhesives are formaldehyde- based, which may result in adverse environmental and health concerns due to the toxic formaldehyde emissions. The decreasing supply of raw materials and the need for formaldehyde-free particleboard have led to focus on research for manufacturing particleboard without using synthetic adhesives. However, binderless or self bonding particleboard which is manufactured without using any synthetic binders may exert inferior physical and mechanical characteristics [2], [3]. Therefore, it would be better to utilize natural binders which are biodegradable, cost effective and at the same time can improve the physical and mechanical properties of the manufactured boards.

In the present study, the *Rhizophora* spp. stems and gum Arabic (GA) are used for the particleboards fabrication. Three different particle sizes of the *Rhizophora* spp with four percentage ratios of the GA are utilized. Field-emission scanning electron microscopy (FESEM) was used to characterize the external morphology of the manufactured particleboards, while; CHNS/O analyser was used to determine their internal elemental composition and evaluate their potential as tissue equivalent material.

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II. Materials And Methods

A. Rhizophora sp. particleboardspreparation

The *Rhizophora* spp. trunks were obtained from Kuala Sepatang, Perak, Malaysia and the gum Arabic was obtained from Sudanese origin and provided by the gum Arabic Company - Natural Prebiotic, Kuala Lumpur, Malaysia. The wood particles were prepared based on Shakhreet et al. [4] 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 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^oC. The mat was then pressed to the required thickness of 0.5 cm for 7 min. The boards were then conditioned in an environment of (70 $\pm$ 5) % relative humidity (RH) and 28 $\pm$ 2^oC before being cut into test specimens. Table I describes the sample identification codes.

TABLE I
SUMMARY OF THE MANUFACTURED *RHIZOPHORA* SP. PARTICLEBOARD SAMPLES BONDED WITH GUM ARABIC.

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

B. Scanning Electron Microscopy Examination

Field emission scanning electron microscopy (FE-SEM) was used to get a comprehensive image of the external structural morphology and spatial relationships in the fabricated particleboards. *Rhizophora* spp. particleboard samples of 0.5 x 0.5 cm^2, with different particle sizes and GA adhesive percentages, were fixed onto specimen holder using double face adhesive tape and were coated with Cadmium using Quorum sputter coater (Q150T ES, UK). The samples were then examined under a scanning electron microscope (LEO SUPRA 50 VP ultra-high resolution analytical field emission scanning electron microscope (FESEM), Germany). Images were captured under conventional secondary electron imaging conditions with an acceleration voltage of 15 kV and at different magnifications (100X, 500X, and 3000X).

C. Analysis of the CHNS composition

The carbon, hydrogen, nitrogen, and sulfur (CHNS) elemental composition of *Rhizophora* spp. particles (RH), gum Arabic (GA), and 5% gum Arabic-*Rhizophora* spp mixture (RH5) was determined using fully automated PerkinElmer 2400 Series II CHNS/O Elemental Analyzer. Portions of finely grounded samples with a mass of no more than 2 mg were weighed in clean containers and introduced into the analyzer. The CHNS mode was used to determine carbon, hydrogen, nitrogen and sulfur in the tested samples, where the sample undergoes oxidative decomposition and the subsequent reduction of nitrogen and sulfur oxides with the production of elemental gases as the final products: carbon dioxide (CO_2), water (H_2O), elemental nitrogen (N_2), and sulfur dioxide (SO_2). The concentration of each element in the sample was calculated automatically using the software supplied with the CHNS/O analyzer. The elemental composition of a sample is expressed in terms of the weight percent of each element in the compound.

III. Results And Discussion

Macroscopic examination of the fabricated particleboards showed smooth homogeneous surface and strong rigid texture. Fig.1 shows the fabricated GA bonded *Rhizophora* spp. particleboard samples

A. Scanning electron microscope examination

Field Emission Scanning Electron Micrographs (FE-SEMs) of the binderless particleboards (0 %GA) and particleboards manufactured with 5% and 15% of GA are shown in Fig. 2 and Fig.3. At the magnification of 500 X, it is obvious that the normal wood tissue microstructure was destroyed and can't be recognized in any of the observed samples. All what can be seen is a uniform homogenous blend of the compressed cell walls, fibers, and ground parenchymatous tissues due to the compression during manufacturing process. A very compact network of fibres was observed on the surface of all the samples with and without gum content which resulted in a highly smooth particleboards' surfaces. Compression reduced the lumen void space, thus increased the density of the boards and consequently enhanced the mechanical properties of the particleboards.

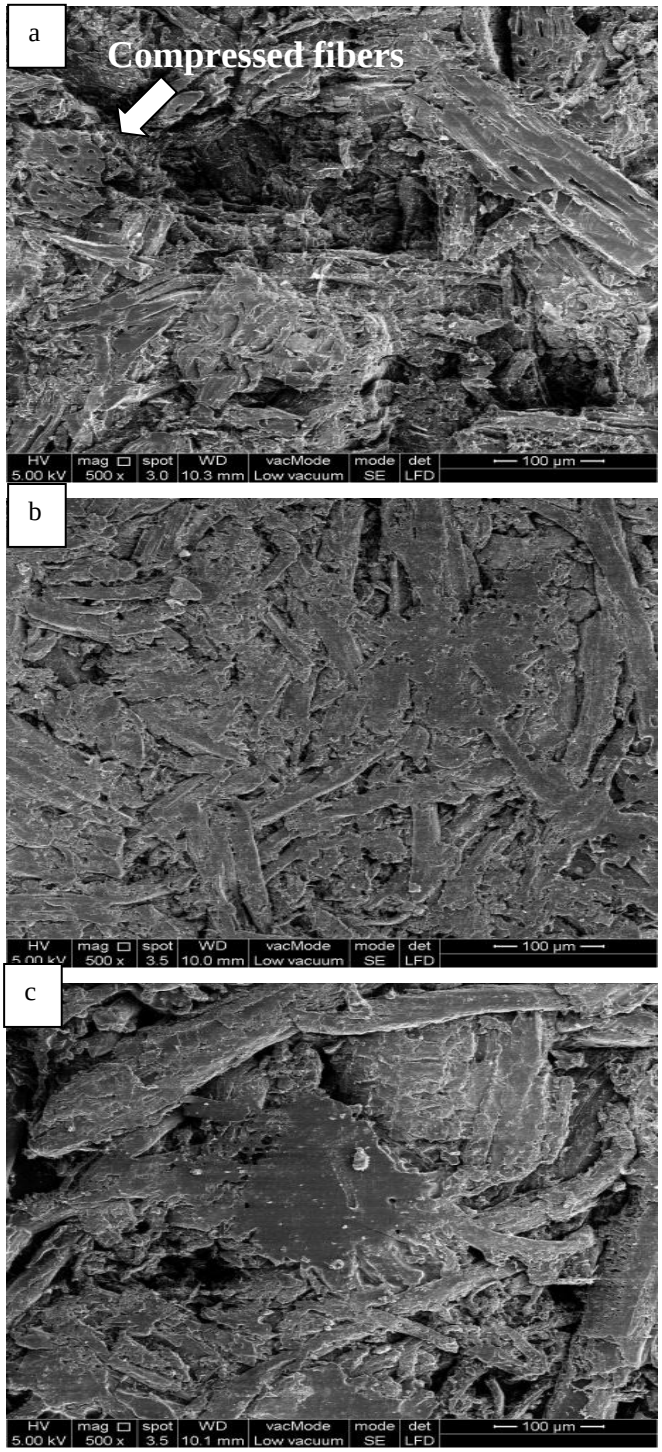

Fig. 2 Field Emission Scanning Electron Micrographs (FE-SEM) of wood particleboards manufactured from *Rhizophora* spp. particles (149-210 µm) with a) 0%, b) 5% and c) 15% of gum Arabic at 500X.

The presences of gum Arabic distributing homogeneously within the cells either coating or filling up in between fibres can also be seen obviously in the samples with 5% and 15% gum Arabic treatment. On some points, the limit between two or more fibres faded, and it was impossible to tell if it was one single fiber or multiple fibers melted one in the others. No spaces can be found in the gum treated samples since the gum filled the empty areas. During the hot pressing, the gum melts, flows, covers the fibers and fills the lumen void spaces, therefore acts as an adhesive that binds the wood particles together. It seems that there is good contact between the wood particles, as can be clearly observed at the high magnification of 3000X in Fig. 3. The interaction between the gum and wood particles contributed significantly to the adhesion of the boards.

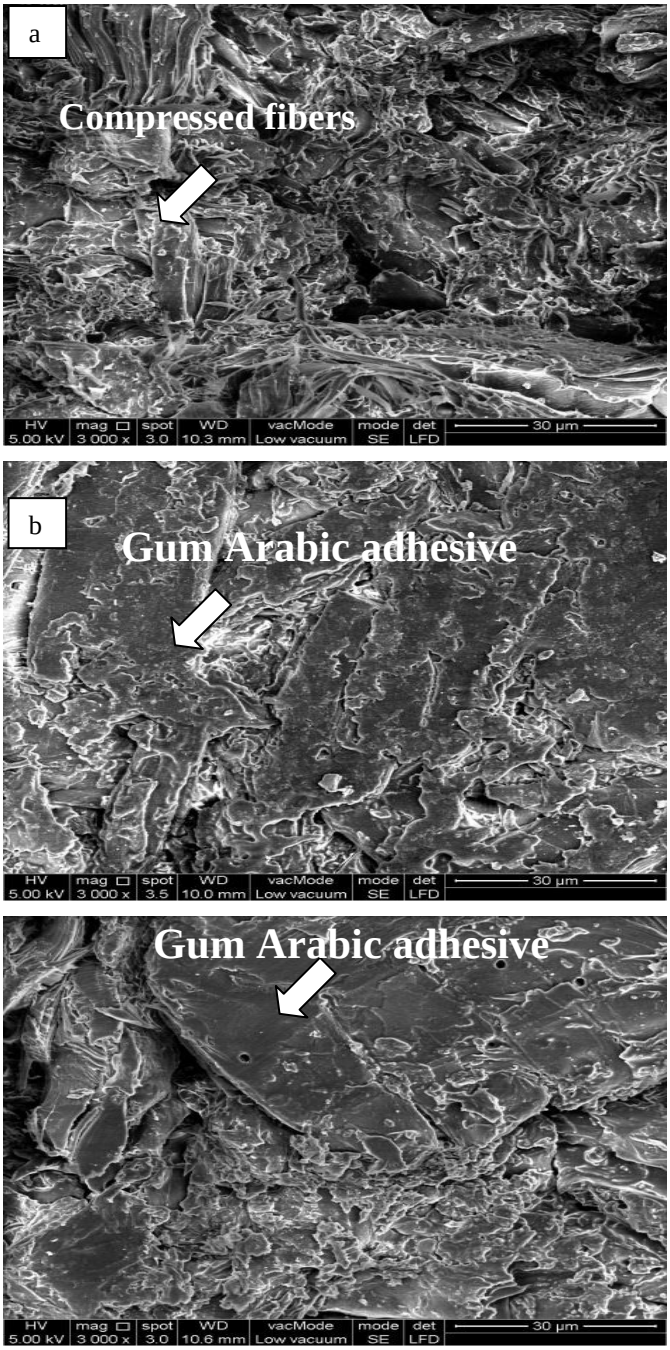

Fig.3 Field Emission Scanning Electron Micrographs (FE-SEM) of wood particleboards manufactured from *Rhizophora* spp particles (149-210 µm) with a) 0%, b) 5% and c) 15% of gum Arabic at 3000X. Arabic gum appears in the micrographs distributing within the cells either coating or filling up in between fibres.

Microscopic study also revealed that B_5 & B_{15} boards made with the gum had better contact if compared to the binderless boards (B_0). This observation supported the results of internal

bonding (IB) characteristics of the particleboards and confirms the enhanced mechanical properties of the GA bonded particleboards. Not much difference between the 5% and 15% GA percentage levels. Based on the FE-SEM observation and previously published IB test results, it could be concluded that gum is an effective natural substance that could be added to the manufactured particleboards to improve their physical and mechanical properties.

B. CHNS Analysis

The weight fractions of each element in the tested sample are presented in Table II.

TABLE II

THE CHNS ELEMENTAL COMPOSITION OF *RHIZOPHORA* SPP PARTICLES, GUM ARABIC POWDER AND GUM ARABIC-*RHIZOPHORA* SPP. MIXTURE.

Sample	*Rhizophora* spp. particles (RH)	Gum Arabic (GA)	5%GA-*Rhizophora* spp. (RH5
Weight (mg)	1.51	1.01	1.77
C (%)	40.96	34.21	42.10
H (%)	5.37	5.30	5.25
N (%)	0.89	0.98	0.65
S (%)	0.45	0.36	0.16

It is shown that the major element in the tested samples is carbon, followed by hydrogen, nitrogen and sulfur, respectively. The RH5 sample had the highest percentage of carbon 42.10%, while GA had a lesser carbon content of 34.21%. The high carbon content of *Rhizophora* spp particles relates to the major constituents of wood that are cellulose ($C_6H_{10}O_{5)}$, lignin ($C_{10}H_{12}O_3$), and hemicellulose ($C_5H_8O_4$), plus minor amounts of other materials including compounds containing nitrogen. The addition of 5% gum Arabic to the *Rhizophora* spp particles increased the carbon content of the sample from 40.96% to 42.10%. This might be due to the chemical composition of gum Arabic which has been reported to be highly heterogeneous, complex mixture of high-molecular weight polysaccharides, proteins and arabinoglacto protein species. It is naturally found as mixed calcium, magnesium, potassium and sodium salts of Arabic acid; that is a complex branched polysaccharide which on hydrolysis yields D- galactose, L-rhamnose, D-glucuromic acid and L-arabinose residues [5], [6], [7].

The knowledge of the elemental composition of tissues is crucial in order to design and construct a tissue equivalent phantom. When the elemental composition of both tissue substitute material and human tissue are not greatly different, it would expected that a properly designed tissue substitute phantom would provide a response very close to that of a tissue equivalent material when used for dose measurements. The elemental composition of several human organs, tissues and some tissue equivalent substances is provided in Table III. The data were obtained from literature [8], [9].

TABLE III

THE ELEMENTAL COMPOSITION OF SOME HUMAN ORGANS, TISSUES AND OTHER TISSUE EQUIVALENT MATERIALS.

Sample	C (%)	H (%)	N (%)	O (%)	Others (%)
Adipose tissue	59.8	11.4	0.7	27.8	Na: 0.1, S: 0.1, Cl: 0.1
Blood (whole)	11.0	10.2	3.3	74.5	Na: 0.1, P: 0.1, S: 0.2, K: 0.2, Cl: 0.3, Fe:0.1
Brain (grey/ white matter)	14.5	10.7	2.2	71.2	Na: 0.2, P: 0.4, S: 0.2, K: 0.3, Cl: 0.3
Breast (mammary gland)	33.2	10.6	3.0	52.7	Na: 0.1, P: 0.1, S: 0.2, Cl: 0.1
Cortical bone	15.5	3.4	4.2	43.5	Na: 0.1, P: 10.3, S: 0.3, Mg: 0.2, Ca: 22.5
Eye lens	19.5	9.6	5.7	64.6	Na: 0.1, P: 0.1, S: 0.3, Cl: 0.1
Muscle (skeletal)	14.3	10.2	3.4	71.0	Na: 0.1, P: 0.2, S: 0.3, K: 0.4, Cl: 0.1
Soft tissue	11.1	10.1	2.6	76.2	Na: 0.1, P: 0.2, S: 0.3, K: 0.2, Cl: 0.2
Acrylic	60.0	8.0	-	32.0	
Paraffin wax	85.0	15.0	-	-	
Polyethylene	85.6	14.4	-	-	
Water	11.2	-	-	88.8	
RH*	41.0	5.37	0.89		S: 0.45
GA*	34.2	5.30	0.98		S: 0.36
RH5*	42.1	5.25	0.65		S: 0.16

*RH, GA, and RH5 refer to the *Rhizophora* spp and gum Arabic samples used in this experiment.

It is obvious from the results of the elemental composition analysis that the *Rhizophora* spp particleboard samples have all the required major elements, such as carbon, hydrogen, and nitrogen, found normally in tissues. The major elemental content of *Rhizophora* spp particleboard samples is more comparable to that of adipose and breast tissues. Therefore, *Rhizophora* spp particleboard samples have the potential to be good representatives of breast tissues and can be used as breast phantom materials. It could be possible to add some modifications on the physical and chemical properties of the *Rhizophora* spp particleboard samples, so that they can be made to have similar elemental composition that mimics human breast tissues at different stages and/or different disease types.

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. *Rhizophora* spp. particleboard samples possess all the required major elements in amounts that are more comparable to that of adipose and breast tissues. Therefore, *Rhizophora* spp. particleboard

samples have the potential to be good representatives of breast tissues and can be used as breast phantom materials. GA bonded particleboards can be recommended to be used as tissue equivalent phantom material for dosimetric applications.

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