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Measurement of mass attenuation coefficients of *Eremurus–Rhizophora* spp. particleboards for X-ray in the 16.63–25.30 keV energy range

E.T. Tousi [a,*], S. Bauk [b], R. Hashim [c], M.S. Jaafar [a], A. Abuarra [a], K.S.A. Aldroobi [a], A.M. Al-Jarrah [a]

[a] School of Physics, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia
[b] Physics Section, P.P.P. Jarak Jauh, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia
[c] Division of Bio-resource, Paper and Coatings Technology, School of Industrial Technology, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia

HIGHLIGHTS

- *Rhizophora* spp. particleboard bonded with *Eremurus* spp. root as a new phantom.
- Mass attenuation coefficient of particleboard was measured in 16.63–25.30 keV range.
- Mass attenuation coefficient particleboard was affected by particle size and %glue.
- Mass attenuation coefficient of particleboard was close to water and young breast.
- Viscosity of *Eremurus* was significantly higher than those of synthetic adhesives.

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ABSTRACT

The roots of *Eremurus* spp. were used as a bio-adhesive in the fabrication of *Rhizophora* spp. particleboards. The mass attenuation coefficients of *Eremurus–Rhizophora* spp. particleboard of six samples with two different weight percentages of the *Eremurus* spp. root (6% and 12%) and three various *Rhizophora* spp. particle sizes (≤ 149 μm, 149–500 μm and 500–1000 μm) were determined by using X-ray fluorescence (XRF) photons in 16.63 keV and 25.30 keV of the photon energy range. The results were compared with theoretically calculated mass attenuations using the XCOM computer program for younger-age (breast 1: 75% muscle+25% fat), middle-age (breast 2: 50% muscle+50% fat), and old-age (breast 3: 25% muscle+75% fat) breasts. The results indicated that *Eremurus–Rhizophora* spp. particleboard is the appropriate suitable phantom in the diagnostic energy region. The mass attenuation coefficient in the low weight percentage of the bio-adhesive and the large *Rhizophora* spp. particle size were found very close to breast 1. Moreover the mass attenuation coefficient of the sample with high weight percentage of the bio-adhesive and small *Rhizophora* spp. particle size was found very close to water as a standard material phantom. In addition, the viscosity of dissolved *Eremurus* spp. root in water could be considerably higher than that of formaldehyde-based adhesives, which affects on some properties such as high strength and high binding.

1. Introduction

Phantoms are simulated systems of the human body that are used in medical physics. Although widely used in clinical dosimetry, water and solid homogeneous phantoms, such as polystyrene and acrylic, are not always feasible (Khan, 2010). Thus, the search for new phantom materials and new methods are still ongoing. Mammography is a technique in medical imaging that is used to detect and diagnose breast cancer or any illness in the breast using low-energy X-ray. Phantoms are especially important in mammography due to their use in the quality control (QC) of mammography equipment. Therefore, the proximity of the dose in the phantom and the real breast tissue ensures high-quality mammography. The mass attenuation coefficient is an important parameter in radiation and medical physics, which is extracted from the Beer–Lambert law in optics science (Beutel et al., 2000). Based on this law, the beams are attenuated exponentially when passing through materials. This attenuation depends on the mass attenuation coefficient, defined as the linear attenuation coefficient (μ) per density (ρ), and is expressed in cm^2/g.

Rhizophora spp. is a type of mangrove trees that grow in the coastal areas of the tropics. They are presently used mainly for charcoal and building materials. Studies have been performed in

* Corresponding author. Tel.: +60 175290481.
E-mail address: ehsan.tousi@yahoo.com (E.T. Tousi).

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the past two decades to determine the possibility of using *Rhizophora* spp. as a phantom material. In 1988, the suitability of *Rhizophora* spp. as phantom material was confirmed for the first time by Sudin et al. The attenuation coefficient of *Rhizophora* spp. was investigated at the photon energy of 59.54 keV by Bradly et al. (1991), and their results were very close to the values of the attenuation coefficient of water. Tajuddin et al. (1996) studied the transmission and scattering properties of *Rhizophora* spp. wood, modified rubber, and water. The scattering and radiographic properties of *Rhizophora* spp. wood and modified rubber were indicated to be similar to that of water. The dose distribution in *Rhizophora* spp. wood and water phantoms were measured using LiF thermoluminescent dosimeters (TLDs) around ^{137}Cs and ^{192}Ir brachytherapy sources (Munem, 1999). The results indicated good agreement for both brachytherapy sources between *Rhizophora* spp. and water phantoms. In addition, the percentage depth dose in the water and *Rhizophora* spp. wood phantoms were compared at 6 MeV photon beam as well as at 5 MeV and 20 MeV electron beams in 2001 (Banjade et al., 2001). The results showed very good agreement between the two phantoms. In 2009, the mass attenuation coefficient was determined within the photon energy range of 15.77–25.27 keV using an X-ray fluorescent (XRF) beam (Shakhreet et al., 2009). The results of this study confirmed that the mass attenuation coefficient of *Rhizophora* spp. is close to that of young-age breast (breast 1), as calculated by the XCOM computer program. The "XCOM: Photon Cross Sections Database" is a computer code, which has been issued by the National Institute of Standards and Technology (NIST) (Hussein, 2011). The XCOM computer code can calculate the photon cross sections for various elements and compounds with atomic or effective atomic numbers less than 100, at 1 keV to 100 GeV of the photon energy range for all photon–matter reactions (Berger et al., 1998), which has been widely used by many researchers to compare the mass attenuation coefficients of the standard materials with their experimental results.

The use of *Rhizophora* spp. raw wood as phantom has some practical limitations. Uniformity in the control of density and other properties throughout the phantom is very difficult. In addition, *Rhizophora* spp. wood gets slimy with mold growth, while cracks and warps appear with time (Marashdeh et al., 2012). The fabrication of *Rhizophora* spp. in the form of particleboards has been considered by some researchers as an alternative.

A particleboard can be generally made in two forms: binderless and using adhesives. The mass attenuation coefficient of *Rhizophora* spp. binderless particleboard at photon energy from 16.59 keV to 25.26 keV was investigated (Marashdeh et al., 2012). The results showed that the mass attenuation coefficient of *Rhizophora* spp. binderless particleboard depends on the particle sizes and closer to the calculated XCOM values in water with decreasing particle size. However, the mass attenuation coefficients of *Rhizophora* spp. binderless particleboard were not very close to the values of the breast tissue in the mammography photon energy range. In addition, its applications are limited by low internal bond and low resistance against water absorption for prolonged time usage in clinical dosimetry (Marashdeh et al., 2011).

Rhizophora spp. particleboards using synthetic adhesives (urea formaldehyde, phenol formaldehyde and phenol resorcinol formaldehyde) were investigated by Surani (2008) and Tong (Ngu, 2009). Their results did not match with the mass attenuation coefficient of water, which significantly varies with that of breast tissue. Moreover the chemical fumes from the synthetic adhesives that may be possibly released from the phantom with passing time may cause some health concerns for staff and patients (Hashim et al., 2011; Marashdeh et al., 2012, 2011).

In the present study, a completely bio-based adhesive was used as a binder to fabricate *Rhizophora* spp. particleboards. This bio-adhesive was made from dried and finely powdered roots of *Eremurus* spp., a genus of perennial flowers that is classified in the *Angiosperm* phylum, and *Monocot* clade (Bryan, 1992). *Eremurus* spp. has been traditionally classified in *Liliaceae* family but has undergone significant revision in the recent year, based on the *Monocot* classification. This genus is newly classified in the order *Asparagales*, family *Xanthorrhoeaceae*, and subfamily *Asphodeloideae* (Bremer et al., 2009). It commonly grows on stony slopes and the steppes of mountains, and then blossoms in June. The root of this plant is thick and glazed, which looks like a starfish. The root contains about 30% gum, which makes it a good quality glue (Komarov, 1985).

The viscosity and melting point of powdered *Eremurus* spp. root were measured. Also, the mass attenuation coefficients of *Eremurus–Rhizophora* spp. particleboards were determined from six samples of powdered *Eremurus* spp. root with two different percentages by weight and three different *Rhizophora* spp. particle sizes using X-Ray Fluorescent (XRF) photons within the energy range of 16.63–25.30 keV. The results were compared with the theoretically calculated mass attenuation coefficients using a photon cross section of the XCOM computer program for young-age (breast 1: 75% muscle+25% fat), middle-age (breast 2: 50% muscle+50% fat), and old-age (breast 3: 25% muscle+75% fat) breasts (Constantinou, 1982).

2. Materials and methods

2.1. Determination of the melting point of Eremurus spp. root as a bio-adhesive

The melting point of the *Eremurus* spp. root plays a very important role in the fabrication of the particleboard. In the present study, differential scanning calorimetry (DSC) was used to measure the melting point of the *Eremurus* spp. root. DSC is a type of thermal analysis technique that is used to study several characterizations of samples and has various applications in sciences and industries. In the experimental method of DSC, the sample and a known reference are heated with a linear temperature gradient between two defined temperatures and the heat of the sample is measured relative to the reference material. The DSC analysis produces a curve that shows the heat flow by milliwatt (mW) against temperature (°C).

2.2. Determination of viscosity of Eremurus spp. root as a bio-adhesive

Viscosity is an important physical property of any adhesives. A *Brookfield DV-II+Pro U.S.A.* viscometer was employed to measure the viscosity of *Eremurus* spp. root. According to the Japanese industrial standard, the spindle of viscometer was utilized with 62.5 rpm speed to measure the powdered *Eremurus* spp. root dissolved in water at different weight percentages of solid content (6%, 10%, 12%, and 15%) at room temperature (JIS, 2003; Wang et al., 2011). The pascal-second (Pa s=kg m^{-1} s^{-1}) is the unit of viscosity in the SI system. The unit of the viscometer was centipoise (cp), which the poise (g cm^{-1} s^{-1}) is the viscosity unit in the cgs system. So, a cp unit is equal to 0.001 Pa s. The viscosity of the *Eremurus* spp. root was compared with that of the tow widespread based-formaldehyde adhesives, urea–formaldehyde (UF) and phenol–formaldehyde (PF).

2.3. Particleboard fabrication

Three steps are involved in making the *Eremurus–Rhizophora* spp. particleboard, as follows:

(1) Preparation of *Rhizophora* spp. particles and *Eremurus* spp. root as a bio-adhesive.