The analysis of palm fiber and palm fiber-$b_4$c potential as a shielding for thermal neutron radiation

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Abstract. The preliminary study towards the ability of palm fiber as a thermal neutron radiation shielding material has been performed. This study is based on the results of SEM-EDX analysis. Moreover, a profound analysis was conducted due to the result obtained. It was revealed that palm fiber consists of several elements, namely; C, O, Na, Si, and Ca, where carbon leads the content level of 70.68%. Carbon element is expected to be able to absorb thermal neutron radiation. The material activation method due to neutron exposure was used to analyze the ability of palm fiber and Palm-$b_4$C fiber to absorb neutron radiation. Gold foil was activated at the Radiography Neutron Facility of National Nuclear Energy Agency (BATAN) PSTBM of Indonesia. Thermal neutron flux at gold foil for both before and after passing through the shielding made from palm fiber was analyzed in the laboratory of AAN PSTBM BATAN. Based on the analysis of thermal neutron flux data, the attenuation coefficients of palm fiber and Palm-$b_4$C fiber were 0.9538 cm$^{-1}$ and 1.399 cm$^{-1}$ respectively. It can be concluded that palm fiber and Palm-$b_4$C fiber has the ability as a strong neutron shielding candidate.

Keywords: Palm Fiber, Neutron Shielding, Boron Carbide

1. Introduction

The use of synthetic fibers has been widely used in the composite industry for the past few decades. However, the environmental impacts and health effects generated from the use of synthetic fibers have been triggered an enhancement for the use of natural fibers as a promising alternative materials [1]. Enhancement for the use of natural fibers is also promoted by its availability, affordability, processing capability, renewal, recycling, and biodegradability [2]. In addition, natural fibers exhibit several other advantages such as comparable special tensile properties, not risk human health, low density and less energy consumption during processing compared to synthetic fibers [3].
Palm tree (*ArengapinnataMerr.*) is a multipurpose tree which all parts of this plant could be utilized. Palm trees have been known for centuries and used by humans for various products. One part of palm tree is palm fiber. In average, the length of palm fiber can grow up to 1.19 m with 1.26 kg m⁻³ density [4]. Palm fiber has long been used but still traditional application such as for roofing materials, brooms, ropes, brushes and others [5,6]. Palm trees come from tropical Asia, widespread in Indonesia, Philippines, Malaysia, Assam-India, Laos, Cambodia, Vietnam, Sri Lanka and Thailand. Palm trees spread widely in Indonesia [2], the area of palm tree in Indonesia reached 60,482 Ha [7]. Notice its abundant potential, it is deemed necessary to increase the economic value of palm fiber from traditional to be an engineering materials that can be used more widely in industry, and certainly environmentally friendly and inexpensive.

Boron carbide is a covalent ceramic material with the stoichiometry formula as B₄C. Boron carbide is known as the hardest material (hardness > 30 GPa), low wear coefficient (∼2 × 10⁻¹⁴ m² N⁻¹), low density (52.52 g cm⁻³), high melting point (∼2540 °C), elastic modulus (45445 GPa) and high thermal conductivity (∼30 Wm⁻¹ K⁻¹) [8] and has been widely used in scientific research for many years [9]. In nuclear science, boron carbide is one of the materials used as neutron absorbers because it has known that elements in main group (B, C, Li, He) are able to absorb neutrons [10].

The purpose of this research is to observe the ability of palm fiber and palm fiber-1%B₄C absorbs thermal neutron radiation to find out whether palm fiber and palm fiber-1%B₄C can be a candidate material for neutron shielding, through analyzing and determining neutron flux when before and after passing through the material using the activation method of gold foil in neutron radiography facility at PSTBM BATAN. Whereas to determine the amount of thermal neutron flux on the foil when before and after passing through shielding, it was analyzed in Neutron Activation Analysis Laboratory (AAN) BATAN PSTBM using Gamma Spectroscopy instrument.

2. Experimental method

2.1. Treated with SEM-EDX
Testing using SEM-EDX aims to identify the content that obtains a view from the surface of the sample which is then computed by software to analyze the composition quantitatively or qualitatively.

2.2. Neutron shielding
Palm fiber was smoothed by using High Energy Milling (HEM) with a frequency of 1000 rpm for 4 x 15 minutes. Shielding sample material was weighed with mass variations 1; 1.5; 2; 2.5; 3; 4 g is then compacted in a vial with its diametrof 2 cm, with a pressure of 2000 kg/cm² and held for about 10 seconds. Whereas for shielding material of palm fiber, the palm fiber that has been smoothed with HEM, part of it is then mixed with B₄C and mixed again using HEM for 10 minutes then printed by compaction in a vial with its diameter 2 cm, pressure of 2000 kg/cm² and held for about 10 seconds as depicted in Fig.1 (a) and (b)

![Figure 1 a. Process to make shielding material](a)

![Figure 1 b. Compaction results](b)
2.3 Gold foil activation

In order to determining thermal neutron flux, it was used the gold foil that have been weighed and glued to shielding material on both sides. The shielding material which has been prepared then arranged in material place where the outside diameter was 250 mm and 120 mm in inside diameter and then irradiated in Radiography Neutron Facility at BATAN PSTBM. The activity of gold foil can be determined by following equation:

\[ A_t = \frac{Cps}{\varepsilon I_\gamma} \]

in which:
- \( A_t \) = Activity (Bq)
- \( C \) = count data (cps)
- \( \varepsilon \) = efficiency detector = 0.0194
- \( I_\gamma \text{Au}^{198} \) = 1,000

To determine the thermal neutron flux in condition of before and after passing the shielding material, the equation is used:

\[ A_t = N\bar{\phi} \sigma \left(1 - e^{-T_{1/2}t}\right) \]

in which:
- \( N \) = the observed isotope atomic count
- \( \bar{\phi} \) = neutron flux (n/cm\(^2\).s)
- \( \sigma \) = the macroscopic cross section of neutron \( \text{Au}^{197} \) (cm\(^2\))
- \( t \) = Irradiation time (sec)
- \( T_{1/2} \) = half-life time \( \text{Au}^{198} \) (sec)

The mechanism to find the coefficient of attenuation is shown schematically in Fig. 2.

![Illustration of Neutron interacted in shielding](image)

Figure-2. Illustration of Neutron interacted in shielding

Whereas to determine the attenuation coefficient using the Lambert-Beer law equation [11]

\[ I = I_0 e^{-\mu x} \]
in which:
I = Neutron flux after passing shielding footage (n / cm².s)
I₀ = Neutron flux before passing shielding footage (n / cm².s)
μ = coefficient of attenuation (cm⁻¹)
x = shielding material thickness (cm)

3. Result and discussion

3.1. SEM-EDX of palm fiber

Composition of palm fibre was clearly shown in Fig. 3 (a),(b) and (c)

![Graph of the relationship between number on energy ranges for three testing point](image)

**Figure 3.** Graph of the relationship between number on energy ranges for three testing point (a) (b) (c) palm fiber

**Table 1.** Content of Palm Fiber Using ZAF Method Standardless Quantitative Analysis

| Element | Energy (keV) | Atomic % Point 1 | Atomic % Point 2 | Atomic % Point 3 |
|---------|--------------|------------------|------------------|------------------|
| C       | 0.277        | 71.97            | 70.92            | 69.14            |
| O       | 0.525        | 27.22            | 28.32            | 29.74            |
| Na      | 1.041        | 0.55             | 0.51             | 0.74             |
| Si      | 1.739        | 0.13             | 0.10             | 0.23             |
| Ca      | 3.690        | 0.13             | 0.14             | 0.15             |
| Total   | 100          | 100              | 100              |

Fitting Coefficient : 0.1468 , 0.1371 and 0.1891
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The purpose of SEM-EDX was to observe whether main class elements contained in palm fiber. From the results using SEM-EDX, it was found that palm fiber has a high carbon content of 70.68%, this can be an early indication that palm fiber has the ability to absorb thermal neutrons.

3.2. Gold foil activation

3.2.1. Palm fiber material shielding

From the results of thermal neutron flux analysis when before and after passing through the palm fiber shielding, it was found that thermal neutron flux declined after passing through the fiber shielding as shown in table 2.

Table 2. Table of neutron flux before and after passing the palm fiber neutron shielding

| No. Material | Thickness (cm) | Ø before (cm⁻¹) | Ø after (cm⁻¹) |
|--------------|----------------|----------------|----------------|
| 1            | 0.2833         | 3.70 x 10¹⁰    | 2.65 x 10¹⁰    |
| 2            | 0.4117         | 3.92 x 10¹⁰    | 2.47 x 10¹⁰    |
| 3            | 0.5317         | 4.04 x 10¹⁰    | 2.29 x 10¹⁰    |
| 4            | 0.6517         | 3.33 x 10¹⁰    | 1.69 x 10¹⁰    |
| 5            | 0.7633         | 3.86 x 10¹⁰    | 1.77 x 10¹⁰    |
| 6            | 1.0250         | 4.18 x 10¹⁰    | 1.47 x 10¹⁰    |

The measurement result of thermal neutron flux in palm fiber material was shown in Figure 4. Based on Figure 4, it was obtained the equation of thermal neutron flux reduction on pure palm fiber \( y = -0.9538x - 0.00613 \) with the attenuation coefficient of shielding material was 0.9538 cm⁻¹.

Figure 4. Graph of thermal neutron flux declines to the thickness of neutron shielding material from the palm fiber

3.2.2 Palm fiber-5% B₄C

From the results of thermal neutron flux analysis when before and after passing through the palm fiber-5% B₄C shielding material, it was found that the thermal neutron flux has declined after passing through the palm fiber shielding material as shown in table 3.
Table 3. Table of neutron flux before and after passing the palm fiber-5% B₄C neutron shielding

| No. | Cpl (cm) | Ø_{before} (cm⁻¹) | Ø_{after} (cm⁻¹) |
|-----|----------|-------------------|-----------------|
| 1   | 0.2898   | 4.11 x 10¹⁰      | 2.13 x 10¹⁰     |
| 2   | 0.4687   | 2.13 x 10¹⁰      | 3.98 x 10¹⁰     |
| 3   | 0.6207   | 3.98 x 10¹⁰      | 1.55 x 10¹⁰     |
| 4   | 0.7752   | 1.55 x 10¹⁰      | 4.31 x 10¹⁰     |
| 5   | 0.9024   | 4.31 x 10¹⁰      | 1.29 x 10¹⁰     |
| 6   | 1.1797   | 1.29 x 10¹⁰      | 4.65 x 10¹⁰     |

The measurement result of thermal neutron flux in palm fiber-5% B₄C shielding material was shown in Figure 5. Based on Figure 5, it was obtained the thermal neutron flux reduction equation \( y = -1.3998x - 0.2982 \), with attenuation coefficient experienced a significant elevation about 1,399 cm⁻¹. It means that with the addition of B₄C 5%, the ability of shielding material absorbs internal neutron radiation increases around 46.68% due to the addition of elements such as boron and carbon.

Figure 5. Graph of thermal neutron flux declines to the thickness of palm fiber-5% B₄C neutron shielding

4. Conclusion
Based on the analysis of palm fiber, it was obtained that a high carbon content of around 70.68% indicated that palm fiber has the ability to absorb thermal neutron radiation. Based on thermal neutron flux analysis when before and after passing through shielding materials, the attenuation coefficient of pure palm fiber was 0.9538 cm⁻¹ while attenuation coefficient of palm fiber-B₄C experienced a significant elevation of 1,399 cm⁻¹ which was about 46.68%. This result indicated that palm fiber and palm fiber-B₄C can be used as thermal neutron shields, which have low density and very small dimensions when compared to neutron shielding which is generally used.
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