Characterization of wood-borax composites as alternative neutron shielding material using neutron radiography techniques

Agus Salim Afrozi, Auring Rachminisari, Rohmad Salam, Asep Nana S
Center for Science and Technology of Advanced Material, BATAN, Serpong
agussal@batan.go.id

Abstract. To protect operators of equipment using neutron radiation, an alternative material is needed as a neutron shielding which is lightweight and has a high neutron absorption. One alternative material that can be used is wood dust. In this study pure wood sawdust and 30% borax-wood composites were investigated as alternatives to shielding neutrons. Mixing wood sawdust and borax was done using HEM (High Energy Milling) for 1 hour, then pressed at 2000 Psi using a manual press with variations in thickness of 5 mm, 10 mm, 15 mm and 20 mm. SEM characterization results show, the grain size of wood in pure wood and 30% borax-wood composites is still quite large around 50 µm, the EDS results show no significant difference in wood content and 30% borax-wood composites. XRD characterization results showed no new phases were formed in the 30% borax-wood composite. The results of observations with optical microscopy showed that 30% borax-wood composite which were compressed did not form pores but were not evenly distributed. From the compressive test data, there was a decrease in the compressive ability of 30% borax-wood composites compared to pure wood dust from 226.6 N to 110.4 N. The neutron absorption test results using the Neutron Radiography technique with the film technique showed the addition of 30% borax to sawdust increased the neutron absorption rate by an average of 19.05% in wood to 20.24% in 30% borax-wood composites and increased the attenuation coefficient of 0.36 cm\(^{-1}\) in pure wood to 0.53 cm\(^{-1}\) in 30% borax-wood composite.

Keywords: composite, wood, borax, shielding, radiography, neutrons

1. Introduction
Neutron radiation besides having the benefit also saves danger to human safety. Operators in running equipment that uses neutron radiation are vulnerable to the danger of exposure to neutron radiation. In the utilization of neutron radiation, a material that can protect and withstand neutron radiation from an object known as shielding neutrons is needed. Therefore in the area where the operator needs to add shielding neutrons. This shielding material is expected to be lightweight, portable and has good neutron absorption, so that its use is easy and practical to move according to operator requirements.

Radiation shielding material is a material that can reduce the intensity of radiation based on the interaction of radiation with the material, by changing the radiation energy into other energy so that the radiation exposure is reduced. Radiation interactions that occur differ depending on the material passed through and the radiation energy so that the ability to withstand radiation for each material is different. Addition of shielding thickness, generally can reduce radiation intensity. If the radiation with a certain intensity penetrates the containment material, the radiation intensity will decrease
exponentially in proportion to the thickness of the retaining material. So it can be assumed that the 
detention ability is only related to the type of material meeting. [1,2]

Materials that can be used as an alternative to shielding neutrons are materials that have a high 
cross section [3], even better if the material has a high hydrogen content [4]. The incoming neutron 
radiation will interact with hydrogen and will affect the neutron absorption energy [5]. A material that 
has a small atomic number such as water, hydrocarbons, cadmium and boron has a large attenuation 
constant when a neutron radiation is passed and vice versa in materials with large atomic numbers 
such as steel, lead and uranium, neutron radiation that passes through only slightly attenuates [6]. 
Some materials that have been investigated as shielding neutrons include UHMW Polyethylene using 
various types of fillers [7,8]. In Indonesia, there are many natural materials which are potential to be 
shielding materials, including wood dust. The use of wood has been dominated as 
construction material. In wood there is a relationship between specific gravity, flexural strength and 
compressive strength [9].

Research on wood material as an alternative to shielding radiation has been done by several 
researchers such as those conducted by Andri Yanyah and Heri Sutanto, but it is still limited to x-ray 
and gamma radiation [10]. This research will examine the ability of sawdust and the addition of borax 
as an alternative to neutron shielding. Some boron compounds in the form of borax are often used as 
mixes or fillers because they have good mechanical qualities [11]. Besides that, borax with the 
chemical formula NaB.O.10H.O contains boron which is very good for absorbing neutrons [6].

2. Materials and Method

Tools and materials
The material used in this research was ulin wood powder and technical borax. The tools used include: 
sifter, mortar, analytical balance, press tool, Olympus BX-51 Optical Microscope, SEM / EDS (Scanning 
Electron Microscopy / Energy Dispersive Spectroscopy), XRD (X-Ray Diffractometer), 
Strograph-5E Compression Test Equipment and RN1 neutron radiographic equipment.

Synthesis of Borax-Wood Composites.
Synthesis of Borax-Wood composites was carried out by mixing wood powder and Borax 30% by 
weight with the dry method using HEM (High Energy Milling) for 1 hour and then pressed using a 
Manual Press Tool at 2000 Psi pressure with a thickness variation of 5 mm, 10 mm, 15 mm and 20 
mm.

Characterization
Borax -wood composite samples were characterized using SEM/EDS to determine grain size and 
elemental content, Optical Microscopes to determine surface and pore conditions of the composites. 
XRD to determine the phase structure and the compressive test was carried out using a Strograph 
VGS-5E compressive test tool to determine the physical properties of the composites.

Neutron absorption Activity Test
Borax wood-composite samples and pure wood samples were tested for neutron absorption ability 
using RN1 equipment with film techniques. The sample is pasted on one side of the film cassette. 
Furthermore, neutron beam shooting was carried out using AGFA D3 film with 90 seconds of 
irradiation time then neutron intensity was calculated before and after passing the material using a 
densitometer.

3. Results and Discussion

SEM Characterization
The results of SEM characterization are shown in figures 1a and 1b.
It can be seen from Figures 1a and 1b that the grain size of wood and 30% borax wood composite is not much different, around 50 µm. Both of them look almost the same grain and do not appear borax material. This is allegedly due to the mixing of borax wood which is still uneven. The EDS results are shown in Table 1 below.

| Element     | Wood (%) | 30% Borax–wood composite (%) |
|-------------|----------|------------------------------|
| C           | 52.07    | 53.98                        |
| O           | 42.10    | 37.94                        |
| Other (Au)  | 5.82     | 8.09                         |

From Table 1 it can be seen that from the EDS results there is no significant difference in the content of wood and 30% borax wood composites. The element boron is not detected in 30% borax-wood composites, this is thought to be due to the very small concentration of the boron element in borax added.

Micro Photo Results
Photomicro results using the Olympus BX-51 Optical Microscope, are shown in Figures 2a and 2b.

From Figure 2a it can be seen that the size distribution of wood grains varies greatly with the shape of grains that are almost the same as the elongated shape. From Figure 2b we can see the uneven distribution of white borax on the sample surface and varying sizes of sawdust. This is due to the
milling process using a ball mill, the time used is quite short, that is 1 hour, which results in the shape and size of the sawdust grains still varying and mixing borax with wood is not homogeneous. From Figures 2a and 2b it can be seen that the compacting done is quite successfully marked by the absence of pores on the entire surface of the sample and the surface of the sample looks solid and sturdy.

**XRD Characterization**

XRD characterization was carried out to determine the phase structure of wood and borax base materials, also to ensure that the conditions of the two materials did not change in the 30% borax-wood composite.

![XRD Characterization](image)

Figure 3. XRD characterization results from wood, borax and 30% borax-wood composite

It can be seen from Figure 3 that the peak pattern formed on the 30% borax wood composite is a combination of the peak pattern of wood and borax. This shows that the addition of 30% borax to wood does not form a new phase, but is a combination of the wood phase and the borax phase. This is due to the mixing of wood and borax to form composites only in physical terms without heating or chemical reactions.

**Compressive Test Results**

The compressive test results are displayed in Figure 4 as follows.

![Compressive Test Results](image)

Figure 4. Compressive test results using Strograph VGS-5E
In figure 4, wood is able to withstand pressures up to 226.6 N before breaking. With the addition of 30% borax the ability to withstand pressure decreased to 110.4 N before breaking. This decrease is due to the ability to bind 30% borax wood composite grains not as well as the bond to pure wood grains.

**Neutron absorption Activity Test**

Absorption ability of neutron shielding material can be determined from the attenuation coefficient of microscopic cross section atomic absorption ($\sigma$). Macroscopic latitude is the sum of the microscopic cross-sections, namely the probability or probability of interaction of neutrons with matter per atom per neutron that arrives. Macroscopic cross section follows the equation:

$$\Sigma_x = N \sigma_x \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (1)$$

Where:

- $\Sigma$ = Macroscopic cross section (cm$^{-1}$)
- $N$ = Material density / material density (core / cm$^3$)
- $\sigma$ = Microscopic cross section

The attenuation coefficient is a reduction in the intensity of radiation that occurs when passing through a material. If a neutron radiation passes through a material, then the reduction in intensity follows the equation:

$$\frac{I}{I_0} = e^{\mu t} \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (2)$$

Where:

- $I$ = Intensity of the neutron beam after passing through the sample (ncm$^{-2}$)
- $I_0$ = Intensity of the neutron beam before passing through the sample (ncm$^{-2}$)
- $\mu$ = Attenuation coefficient (cm$^{-1}$)
- $t$ = Thickness of the material (cm). [6]

The neutron absorption test results with RN1 are shown in table 2.

**Table 2.** Absorption and attenuation of wood and borax-wood composites

| Thickness (Cm) | Intensity | Absorption (1 - I/I$_0$) x100% | Attenuation |
|----------------|-----------|---------------------------------|-------------|
|                | Wood (%)  | Borax--wood composite (%)       | Wood (%)    | Borax--wood composite (%) | Wood (%) | Borax--wood composite (%) |
| 0.00           | 2.23      | 2.26                            | 0.00        | 0.00                      | 0.00     | 0.00                      |
| 0.50           | 2.00      | 1.70                            | 10.06       | 24.96                     | 0.21     | 0.57                      |
| 1.00           | 1.53      | 1.27                            | 23.68       | 25.00                     | 0.38     | 0.57                      |
| 1.50           | 1.21      | 1.06                            | 20.94       | 16.82                     | 0.41     | 0.51                      |
| 2.00           | 0.95      | 0.91                            | 21.52       | 14.18                     | 0.43     | 0.46                      |

Average: 19.05 20.24 0.36 0.53

From table 2 it can be seen that the addition of 30% borax to wood can increase the absorption of neutrons from 19.05% to 20.24%, but the increase in neutron absorption is less significant. The average attenuation also increased with the addition of 30% borax from 0.36 cm$^{-1}$ in wood to 0.53 cm$^{-1}$ in 30% borax wood composites as shown in Figure 5.
Figure 5. Graph of attenuation increase with the addition of 30% borax

From Figure 5 it can be seen that attenuation has the highest increase in thickness of 0.5 cm and at a thickness of 2 cm, the addition of 30% borax only slightly increases the attenuation of wood.

4. Conclusion

From the research that has been done, it can be concluded that, wood dust has a neutron absorption ability of 19.05% and attenuation value of 0.36 cm\(^{-1}\). The addition of 30% borax to wood can increase the neutron absorption ability to 20.24% and increase the attenuation value to 0.53 cm\(^{-1}\) but will reduce the ability to withstand the pressure from wood that was originally 226.6 N to 110.4 N. The optimum thickness of the addition of 30% borax was obtained at 0.5 cm which increased the neutron absorption capacity of the wood from 10.06% to 24.96% and the attenuation value in wood 0.21 Cm\(^{-1}\) to 0.57 cm\(^{-1}\).

Wood dust can is used as an alternative to neutron shielding and is even more effective when 30% borax is added.

5. Acknowledgments

Thanks to Ka. BK2K, Ka. Sub Bid KKPR, Sumaryo, S.ST, Dra. Deswita, Agus Sudjatna, AMd., Drs. Bambang Sugeng, MT and KPTF in PSTBM who have helped a lot in testing, characterizing and compiling this paper.

6. References

[1] Cember Herman, 1983, Introduction to Health Physics, Second Edition, Pergamon Press, New York
[2] Japeri, 2013, Penentuan Koefesiensi Serapan Kayu Bangkirai (SHOREA LAEVIFOLIA) Dan Perbandingannya Terhadap Timbal (Pb) Sebagai Dinding Ruangan Radiologi Diagnostik, Youngster Physics Journal, Semarang
[3] Juliyani, Sutiarso, Setiawan, Kristianti, 2012, Karakterisasi Bahan Pelindung Neutron B2O3 dengan Teknik Radiografi Neutron, Prosiding Pertemuan Ilmiah Ilmu Pengetahuan dan Teknologi Bahan, Serpong.
[4] Kim J, Lee B.C, Uhm Y.R, Miller W.H, 2014, Enhancement of Thermal Neutron Attenuation of Nano-B4C, B-N Dispersed Neutron Shielding Polymer Nanocomposites, Journal of Nuclear Material, Volume 453, Korea
[5] Elmahroug Y, Tellili B, Souga, C, 2013, Calculation of Gamma and Neutron Perisai Parameters for Some Materials Polyethylene-Based, International Journal Of Physics And Research (IJPR), Volume 3.
[6] Domanus J.C, 1992, Practical Neutron Radiography, Commission of the European Communities Radiography Working Group, Kluwer Academic Publishers, London
[7] Winda Surya Bery, Dian Fitriyani, Elvaswer, Enny Zavianti, Mardiyanto, Abu Khalid Rivai, dan Sulistioso Giat Sukaryo, 2016, Pengaruh Penggunaan Teknik Blending dan Kompaksi Terhadap Morfologi Komposit Polimer UHMWPE-Na2B4O7.5H2O Sebagai Bahan Perisai Radiasi Neutron Termal, Jurnal Ilmu Fisika

[8] Enny Zarvianti1, Dian Fitriyani, Elvaswer, Winda Surya Bery, Abu Khalid Rivai, Mardiyanto dan Sulistioso G.S. 2017, Karakterisasi Bahan Perisai Radiasi Neutron Ultra High Molecular Weight Polyethylene Dengan Filler GdO. Menggunakan Teknik Radiografi Neutron, Jurnal Ilmu Fisika

[9] Vogel, 1990, *Text Book: Analisis Anorganik Kualitatif Makro dan Semimikro*, Jakarta : PT. Kalman Media Pustaka

[10] Andri Yanyah dan Heri Sutanto, 2015, *Penentuan Nilai Koefisien Serapan Bahan Dan Dosis Radiasi Pada Variasi Kombinasi Kayu Dan Alumunium*, Youngster Physics Journal Vol. 4

[11] Ozalp, M, 2008, *The Investigation of Borax Pentahydrate Influences With Double Components in Varnish Applications of Wood Materials*, Journal: Wood Research, 53,4, 121-128