DEVELOPMENT OF COST-EFFECTIVE AND READILY AVAILABLE MATERIALS FOR NEUTRON SHIELDING: A COMPARATIVE STUDY OF NATURAL RUBBER-BASED COMPOSITES

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EXTENDED ABSTRACT

INTRODUCTION

Nuclear technology is expanding rapidly in Thailand for use in research and medicine. The country's first BNCT (Boron Neutron Capture Therapy) center, which will be used for research and cancer treatment, is currently being established at Suranaree University of Technology (SUT). Furthermore, as part of its national energy strategy, Thailand is considering the implementation of Small Modular Reactors (SMRs) in the future. The need for efficient and reasonably priced neutron shielding materials is growing with the increasing use of neutron sources. Currently available commercial materials, such as silicone composites containing boron carbide (B_4C) and borated polyethylene (BPE), are effective but expensive and rely on imports. This work investigates the development of natural rubber (NR) composites, incorporating boron compounds, as cost-effective and locally available alternatives for neutron radiation shielding. Moreover, this study evaluates the neutron attenuation performance of NR composites using boric acid, borax, and B_4C, and compares their effectiveness to commercial shielding materials.

METHODOLOGY

For this study, natural rubber (NR) composites were made using Thai natural rubber of STR 5L grade as the base polymer matrix. Various formulations of neutron absorber additives were used at a constant concentration of 50 wt%, including boric acid (H_3BO_3), borax ($Na_2[B_4O_5(OH)_4]\cdot 8H_2O$), and boron carbide ($B_4C$). A standard rubber compounding formulation was employed to ensure proper processing and vulcanization. At 30 phr (Parts per Hundred Rubber), carbon black (N330) was added to the mixture to improve the mechanical properties of the composite, due to its fine particle size, good dispersion, and reinforcing efficiency. Stearic acid and zinc oxide (ZnO) were added as activators to promote vulcanization at 2 and 4 phr, respectively. The primary accelerator in the curing system was CBS (N-cyclohexylbenzothiazole-2-sulfenamide) at 0.5 phr, the secondary accelerator was TMTM (tetramethylthiuram monosulfide) at 0.6 phr, and the vulcanizing agent was sulfur at 2 phr.

To ensure even dispersion of chemicals and fillers within the rubber matrix, the rubber and all additives were first mixed in a laboratory-scale internal mixer. For 25 minutes, the mixing was done at 60 ºC (degrees Celsius). The rubber compound was then transferred to a two-roll mill for rolling into sheets. Before molding, it was kept at room temperature for a full day to allow for stress relaxation and pre-vulcanization stability. The molding was carried out by a hydraulic compression molding press (LP20-B model) at 150°C at the optimum time of each formula as measured by a moving die MDR 3000 rubber curing analyzer, following the ASTM D 5289 standard, which measures the torque response of rubber during curing to identify the optimum vulcanization time.

Neutron tomography or neutron imaging was used to calculate the linear attenuation coefficient (μ) value, which is a neutron shielding property of materials. The experiment was performed at the research reactor of the National Institute of Nuclear Technology (Public Organization). The LiF/Zn(Ag) scintillator was used to mount sample material with a thickness of 0.5 cm in the experiment. The emitted light was reflected by a mirror and subsequently captured by the CCD camera while the samples were irradiated with neutrons. The TIFF format was used to record the image file. Neutron imaging data were used to calculate the brightness fraction (Eq. (1)), which served as the neutron transmission factor (I/I_0) in the attenuation equation

(Eq. (2)). I_0 is the difference in brightness between the images taken when the beam is open beam and off beam (dark beam), while I is the difference in brightness between the images taken with the sample material mounted and the dark beam. All quantitative analyses and image processing were conducted using ImageJ 1.53t. Figure 1 shows an example of the neutron imaging outputs used to derive the attenuation data.

$$Brightness\ fraction = \frac{Image\ brightness_{\text{sample material}} - Image\ brightness_{\text{dark-beam}}}{Image\ brightness_{\text{open-beam}} - Image\ brightness_{\text{dark-beam}}} \tag{1}$$

$$I = I_0 e^{-\mu t} \tag{2}$$

The brightness fraction was used as the neutron transmission factor (I/I_0) in calculating the linear attenuation coefficient (μ) of each sample rubber composite material at thickness (t).

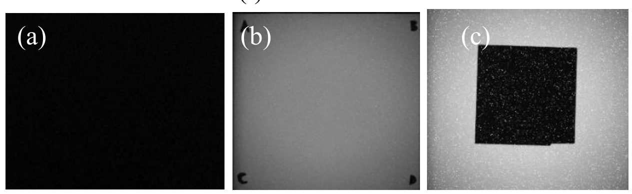

Fig. 1. Neutron imaging results: (a) Open-beam, (b) Dark-beam, (c) Sample with commercial B_4C-silicone.

RESULTS

The composite containing boron carbide exhibited the maximum attenuation among all the samples, with a linear attenuation coefficient of 4.9539 cm^{-1}. The commercial B_4C-silicone material (5.2346 cm^{-1}) performed quite similarly to this. Additionally, the boric acid and borax composites showed established efficacy with coefficients of 4.1589 cm^{-1} and 3.7416 cm^{-1}, respectively. In contrast, the pure NR control sample only showed minor shielding with a value of 0.6991 cm^{-1}.

The NR/B_4C, NR/Boric acid and NR/Borax composites required only 1.0567 cm, 1.2587 cm and 1.399 cm in thickness, respectively, to provide shielding equivalent to 1 cm of the commercial B_4C-silicone product. Achieving the same shielding effect with pure NR would require a thickness of 7.4875 cm. While B_4C offered the highest shielding efficiency, borax emerged as the most cost-effective option, balancing performance with affordability.

CONCLUSION

Natural rubber composites incorporating boron-based additives especially borax and boric acid exhibit promising neutron shielding properties and offer a low-cost, locally sourced alternative to commercial materials. The results confirm that NR-based composites can achieve effective attenuation while supporting sustainability and economic development. However, challenges remain regarding long-term durability under irradiation and the potential degradation of boron compounds. Future work will focus on assessing radiation resistance and mechanical aging under prolonged neutron exposure, in additionally optimizing filler concentrations for improved performance, moreover, developing multilayer composite designs to further enhance shielding efficiency in real-world applications, such as BNCT.

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