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Preparation, shielding properties and mechanism of a novel neutron shielding material made from natural Szaibelyite resource

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ABSTRACT

In this paper, different amounts of Szaibelyite (100, 300, 500, 700 and 900) were used to prepare Szaibelyite/epoxy resin composites for neutron shielding. Microstructures of fracture surfaces of the prepared composites were tested by scanning electron microscope while the neutron shielding properties were determined by Am-Be neutron source. It was found that the shielding percentage of all composites increases with the addition of Szaibelyite as well as the thickness of composites increment. M5 was found to be the best neutron shielding composite, the shielding percentage was nearly 100% when the thickness of M5 chosen to be 1.5 cm. Furthermore, the shielding mechanism of M5 for neutron shielding could be concluded as follows: Firstly, H, O, C, Fe and B-11 isotope contained in M5 slowed down the neutron to thermal neutron, which then absorbed by the B-10 isotope. According to the achieved results, the performance of the new neutron shielding material owns the value of practical application.

1. Introduction

Due to the rapid development in radiation shielding technology, ionizing sources are used widely in our society, such as neutrons, gamma ray and X-ray. Neutron in particular is used in different applications, such as industry, radiotherapy, neutron imaging, elemental analysis and biological applications, etc. (Örs et al., 2017; Lombardi et al., 2015; Mireles et al., 2012; Seymour et al., 2017). However, excessive ionizing radiation will harm the human body. Thus, suitable shields are necessary for the protection against this harmful radiation (Dong et al., 2017a). Materials containing boron, hydrogen and rare earth are the mainly shields for neutron. Many attempts have been reported in the literature to study the neutron shielding materials. Cao et al. (2010) prepared UHMWPE/Sm_2O_3 for this purpose; Chai et al. (2015) had studied the neutron shielding composite based on methyl vinyl silicone rubber. In addition to that, Korkut et al. (2012) have investigated the neutron shielding properties of some boron containing minerals, Park et al. (2015) determined the characteristics of the neutron shielding material made out of B_4C and 6061Al, Hayashi et al. (2009) studied some materials contain relatively high amount of hydrogen for neutron shielding. However, these excellent neutron shielding materials are somehow expensive. Because of its low cost and easy preparation process, concrete shields had been widely studied. Yılmaz et al. (2011) had investigated neutron shielding performance of some concrete shields. Yarar and Bayülken (1994) and Orak and Baysoy (2013) prepared the concrete with some low cost boron minerals. Nevertheless neutron radiation on the concrete would make the water in the shields lost, then the structure of concrete would be broken (Pugliesi and Andrade, 1997). Besides, some shortcomings would be caused in the preparation process of concrete, for example, cracks (Abdo et al., 2003).

Recently, research interest on epoxy resin was found useful due to their different special properties such as good corrosion resistance, good radiation damage resistance and excellent stability. Epoxy resin has very extensive application in the field of neutron shielding materials, floor painting in radiation facilities and for nuclear fuel casks (Abdo et al., 2003; Okuno, 2005; Turgay et al., 2013). Adeli et al. (2016) studied the B_4C/Epoxy resin neutron shielding material. Korkut (Korkut et al., 2010) evaluated some boron compounds/epoxy resin for neutron shielding. Li et al. (2011) tested some neutron shielding material with boron-containing ores.

In the Liaoning Province of China, Szaibelyite is one of the mainly mineral deposits containing boron element, while the mainly utilization methods for Szaibelyite are applied as the raw materials for borax

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production and boric acid production, and emit the gaseous waste, liquid waste and solid waste (An and Xue, 2014). However, boron is well known for its excellent shielding property for neutron and has very extensive applications (Adeli et al., 2016; Korkut et al., 2010; Li et al., 2011; Khong et al., 2016). To our knowledge, the Szaibelyite has never been applied to make neutron shields. Besides, similar to Szaibelyite, Abdo et al. (2003) made ilmenite/epoxy composite for neutron shields. Okuno (2005) had made the colemanite/epoxy resin composites for neutron shielding. As reported by authors, it was found that performance of the new material is suitable for practical applications. Li et al. (2011) tested some neutron shielding material with boron-containing ores. However, the shielding mechanism has not been investigated. Thus the method to utilize the useful ore in the field of nuclear radiation protection materials has been proposed in this paper. Epoxy resin and Szaibelyite are chosen to be the raw materials to prepare the proposed neutron shielding material. The Am-Be neutron source was used to test the shielding properties of the composites. Besides, the shielding mechanism has been studied in this paper. The research provides a new utilization way for Szaibelyite. Simultaneously, it provides a new low-cost neutron shielding material for floor painting in radiation facilities, nuclear fuel casks, repairing the shortcomings in concrete shields.

2. Experimental work

2.1. Materials

The raw materials used in this paper were Szaibelyite (density = 2.58 g/cm^3, Fengcheng Iron and Steel Group Co. Ltd., China), Epoxy resin (E51, Blue Star Chemical New Material Co. Limited, China), Polyamide Curing Agent (651, Blue Star Chemical New Material Co. Limited, China). Table 1 and Fig. 1 show the chemical composition (X-ray fluorescence spectrometer, ZSXPrimus II, Rigaku Corporation, Japan) and XRD pattern (X-ray diffractometer, PW3040/60, Cu 40 kV, 45 mA, PANalytical, Netherlands) of Szaibelyite respectively. B, O, Mg, Si are the mainly elements contained in Szaibelyite. Main compounds are $Mg_2(B_2O_5)(H_2O)$ and $Mg_3(Si_2O_5(OH)_4)$.

2.2. Preparation of the samples

In this work, the preparation process for shielding materials was as follows: Firstly, Szaibelyite was crushed and sieved by 60 mesh. Then the Szaibelyite powder was dried at 120 °C for 10 h. After that, the powder, epoxy resin and polymide curing agent were mixed, besides, anhydrous ethanol was used as the diluent to make the mixture uniformity. Furthermore, the mixture was dehydrated under the condition of vacuum. Last, the mixture was poured into the mold under room temperature curing for 24 h, the three dimensions of the mold was 200 mm*60 mm*5 mm. Shielding composites would be got after demoulding process. Photos of all samples were shown in Fig. 2. Compositions (mass ratio) and densities of shielding composites were shown in Table 2.

2.3. Microstructure analysis

Microstructure of the fracture surfaces of shielding composites were characterized using scanning electron microscope (SEM, S3400N, HITACHI, Japan).

Table 1
Chemical composition of Szaibelyite.

Element	B	O	Mg	Al	Si	Ca	Fe
Mass fraction (%)	5.065	47.502	31.807	0.455	12.066	2.004	1.101

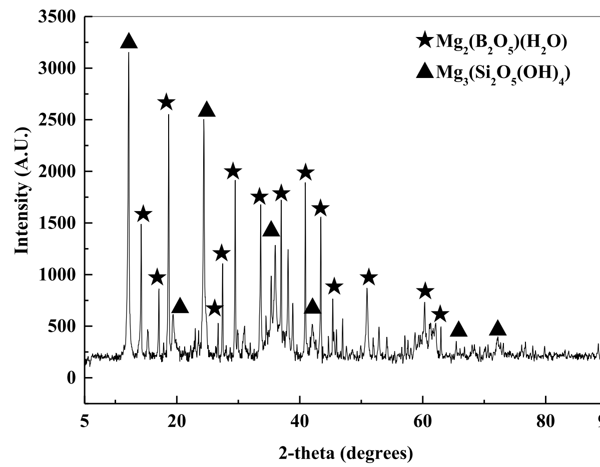

Fig. 1. XRD pattern of Szaibelyite.

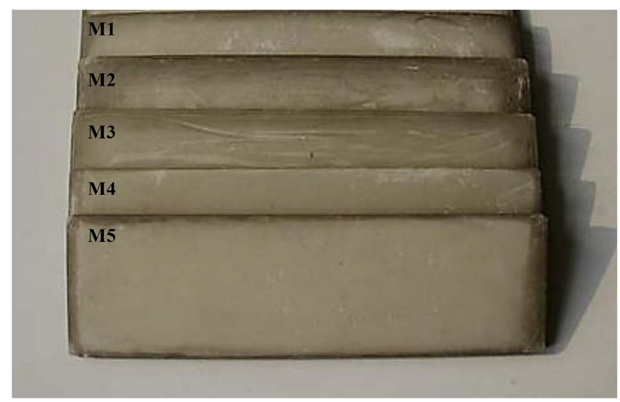

Fig. 2. Photos of all samples in the paper.

Table 2
Compositions and densities of neutron shielding composites.

Sample	Epoxy resin (E51)	Polyamide curing agent (651)	Szaibelyite	Density (g/cm^3)
M1	100	60	100	1.36
M2	100	60	300	1.68
M3	100	60	500	1.74
M4	100	60	700	1.82
M5	100	60	900	1.86

2.4. Neutron shielding measurement

Shielding property of the composite for neutron was tested by Am-Be neutron source (Flux rate is 8×10^6 n/cm^2•s, average energy is 4.5 MeV and half-life is 432 years) under room temperature. Besides, 7 cm thickness polyethylene was set between the source and the samples to get the slow neutron field for testing. The He-3 proportional counter was used as a detector in this work. Furthermore, the distance between activation center and detector was 50 cm, and the shielding composites were set in front of the detector at a distance of 5 cm. The detector counting time was 120s. Moreover, the shielding composites and the detector were surrounded by 2 mm thickness cadmium plate to prevent neutron scattering of testing environment from affecting the efficiency of detector. Fig. 3 shows the schematic diagram of test devices used for neutron shielding. Shielding percentage for each shielding composite was calculated as follows (Li et al., 2011):

$$P = \frac{(I_0 - I_b) - (I - I_b)}{I_0 - I_b} \quad (1)$$