Improving Neutron Shielding Capacities of Galena and Barite Hybrid Fiber Heavyweight Aggregate Concrete for Nuclear Reactor

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Abstract: Biological shielding of nuclear reactors is an important interest and diminishing the intricacy and cost of these installations is an important interest. In this paper, we used galena minerals and barite for the production of a hybrid fiber heavyweight aggregate concrete. Galena minerals that exist in many parts of Iran were used in the concrete mix design. Barite is an important chemical element for neutron absorption processes. The cross-section in matter and neutron capture is a utilizable cause to explain the neutron shielding characteristics of samples. Neutron cross-section measurements of samples were done by using a source of 4.5 MeV neutrons. Cross-section and neutron capture of each sample were calculated by using the Geant 4 Monte Carlo code. As a result, the use of appropriate galena concentration and barite and the use of monofilament polypropylene fiber with steel fiber can improve cross cross-section value of hybrid fiber heavyweight aggregate concrete and enhance the properties of neutron shielding.

Key-words: Galena, barite, neutron cross section, Geant 4 Monte Carlo code, hybrid fiber heavyweight aggregate concrete, shielding

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1. Introduction

Hybrid fiber heavyweight aggregate concrete is a multi-user and it's usually accustomed as a radiation shielding material as a result of being cheaper, easier molded into compound shape, good structural, and appropriate as neutron shielding materials compared to other shielding materials. Y. Abdoullah et al. [1] investigated that most concrete is a composite material consisting of aggregate, sand, water, and cement. Radiation shielding of nuclear reactors is an expensive and very complex process. Pavlenko VI et al. [2] have studied that a nuclear reactor usually needs two shields; a shield to guard the walls of the reactor from radiation harm and at the same time reflect neutrons back into the core; and a biological shield to guard people and the environment. The biological shield decreases the rank of Gamma radiation and neutrons to current dose limits. The biological shield is composed of many centimeters of very high-density concrete. S.M.J Mortazavi et al. [3] found that in nuclear reactors, neutron radiation is the largest difficult to shield and hydrogen is the largest efficient element in decelerating (thermalizing) neutrons over the whole energy spectrum. The largest of the hydrogen in concrete normally displays in the format of water in that hydrated during cement curing and aggregate setting and free water streaming in the porousness of concrete. T. Korkut et al. [4] investigated that Boron is an influential chemical element for neutron absorption procedure. It has an important interest in shielding technology because of its flawless shielding characteristics. Baştürk M et al. [5] have obtained that it is an influential absorber used in neutron shielding materials. There exist various investigations on radiation shielding by boron mixtures [6-10]. Concrete is a frugal and efficient material for shielding reactors. High-density concrete has higher linear gamma and neutron attenuation properties compared to regular concrete. Sun H et al. [11] investigated that concrete is made up of Portland cement, sand, aggregate, and water and is one of the largest ordinary materials used in the construction of commercial buildings. Presently regular concrete (density about 2350kg/m3) is greatly used for superficial and orthovoltage radiotherapy rooms [12].

Galena (PbS) is the main lead mineral [13]. Galena have too cerussite (PbCO3), plattnerite (PbO2) and anglesite (PbSO4). Galena is a considerably dense material, having a density of 7400-7600 kg/m3, so it is closely as dense as iron. The chemical composition and physical properties of Galena are summarized in Table 1.

Baryte or barite (BaSo4) is a mineral consisting of barium sulfate [14]. The baryte group consists of baryte, celestine, anglesite, and anhydrite. Baryte is generally white or colorless and is the main source of barium. Baryte and celestine form a solid solution (Ba, Sr) SO4 [15]. The chemical composition of the Barite mineral is summarized in Table 2.

In a nuclear reactor, for radiation shielding implementation, a particular mixture of Portland cement and sand was used, while boron was doped with Portland cement to create concrete as a thermal neutron absorber and decrease radioactivity by thermal neutron (Atsuhiko et al, 2004).

The principal goals of this study are to acquire neutron cross-section and neutron capture via Geant4 Monte Carlo code for samples. Cross-section and neutron capture of our hybrid fiber heavyweight aggregate concretes is summarized in Table 4.

2. Material and Methods

The starting materials consisted of galena, barite, cement, water, plasticizer, and many kinds of fibers.

Galena minerals were used for the production of high-density concrete. To be used as a shield in nuclear reactors, concrete must include a large amount of water. Higher water content makes concrete more efficient than regular concrete. In this study, 5 types of concrete mixes were produced. The concentration of galena, barite, and fibers in concretes is shown in Table 3. The cross-section of hybrid fiber heavyweight aggregate concretes is shown in Fig. 1. Neutron capture of hybrid fiber heavyweight aggregate concretes is shown in Fig. 2. Absorbed dose by detector of hybrid fiber heavyweight aggregate concretes is shown in Fig. 3.

A radiation test was carried out by exposure to neutron source 241Am-Be (number of events processed 1000000).

MONTE CARLO SIMULATION

The Geant4 program is a useful simulation device for a multitude of applications in high-energy physics. Geant4 can simulate the interaction and propagation in matter of neutrons in a shielding plan. We obtained cross-section and neutron capture via Geant4 Monte Carlo code. In the first place, atomic stoichiometric and densities of samples have been entered. In second place simulation has been started for 1000000 primary neutron particles. Then in the practical section absorbed dose by a detector is obtained.

3. Results and Discussion

The cross-section and neutron capture are influential factors in determining the neutron shielding characteristics of the sample. There is no simple scaling law for the neutron linear attenuation coefficient (Σ). But the cross-section is described and denoted by Σ for neutron. The linear attenuation coefficient has units of inverse length, generally pointed out by cm^{-1}. The microscopic extent of neutron interaction with matter is called the cross-section (σ). Cross section depicts the effective cross-sectional region to neutrons represented by each nucleus of attenuating materials. The units are traditionally the barn where 1 barn is equivalent to 10^{-24} cm^{-2}.

The neutron cross-section has been measured by a neutron detector. The cross-section and neutron capture have been obtained from the Geant4 Monte Carlo code. The measured values of cross section and neutron capture by using Geant4 are shown in Table 4. As can be seen from Table 4 cross section is increasing with the using of monofilament polypropylene fiber in the samples and decreasing absorbed dose by a detector of hybrid fiber heavyweight aggregate concretes. It is seen successfully that the neutron cross-section is strongly dependent on the use of monofilament polypropylene fiber in the concretes and as can be seen from Fig. 1 the B5 sample has high cross section value and low absorbed dose rate. So, it has high neutron shielding properties in comparison to other samples.

Also, the measured values of neutron capture by using Geant4 are shown in Fig. 2. As essentially indicated above, the use of monofilament polypropylene fiber effects on neutron shielding capability of matter. Thus, as can be seen from Fig. 1, fig.2, and Fig. 3 B5 is a more effective shielding material because it has a high cross-section, high neutron capture values, and low absorbed dose rate.

4. Conclusions

We have investigated in the present study, the fast neutron shielding properties of galena (PbS), barite, and different percentages of galena with many kinds of fibers by using experiment and simulation processes. The results of this research have provided new comments about the cross-section of fast neutrons through materials including different percentages of galena, barite, and many kinds of fibers. Neutron cross-section and neutron capture are largely dependent on the galena and fibers in our samples. Because of the high cross-section of B5, it has better-shielding properties than other samples. These materials can be used for building walls of nuclear energy centrals, as moderators for nuclear reactors, in nuclear medicine departments and nuclear investigation centers, etc., to protect damages from neutron particles.

Properties	Galena
Chemical composition	Lead Sulfide (PbS)
Molecular weight	239.26g
Lead content	86.59% Pb 13.40% S
B_2O_3 content	---
stiffness	2.5
Density (g/cm^3)	7.0-7.5
Color	Gray

Table1. Physical and chemical composition of the galena mineral used in this study

Composition	**Content (%)**
SiO_2	0.78
Al_2O_3	0.21
Fe_2O_3	0.07
CaO	0.88
MgO	1.01
SrO	0.70
MnO	0.10
K_2O	0.04
Tio_2	0.02
$BaSo_4$	9.00

Table2. Chemical composition of the Barite mineral used in this study

Code	Content
B1	%100 Barit
B2	%70 Barit + %30 Galena
B3	%70 Barit + %30 Galena + Steel fiber
B4	%70 Barit + %30 Galena + Steel fiber + Multifilament polypropylene fiber
B5	%70 Barit + %30 Galena + Steel fiber + Monofilament polypropylene fiber

Table3a. The code of concretes

Composition	B1	B2	B3	B4	B5
Water	192.5	192.5	192.5	192.5	192.5
Cement	112.9	112.9	112.9	112.9	112.9
Air	10.0	10.0	10.0	10.0	10.0
Plasticizer	3.2	3.2	3.2	3.2	3.2
Aggregate	681.4	681.4	671.4	668.4	668.4
Barite	-	477.0	470.0	467.9	467.9
Barite 8/16	170.4	119.2	117.5	117.0	117.0
Barite 4/8	170.4	119.2	117.5	117.0	117.0
Barite 2/4	170.4	119.2	117.5	117.0	117.0
Barite 0/2	170.4	119.2	117.5	117.0	117.0
Galena	-	204.4	201.4	200.5	200.5
Galena 8/16	-	51.1	50.4	50.1	50.1
Galena 4/8	-	51.1	50.4	50.1	50.1
Galena 2/4	-	51.1	50.4	50.1	50.1
Galena 0/2	-	51.1	50.4	50.1	50.1
Steel fiber	-	-	10.0	10.0	10.0
Multiflament polypropylene fiber	-	-	-	3.0	-
Monoflament polypropylene fiber	-	-	-	-	3.0

Table3b. Content of composition of hybrid fiber heavyweight aggregate concrete in 1000 dm^3

Sample	Equivalent dose rate (μSv/saat)	Absorbed dose by detector (μSv/saat)	Cross sectıon (cm^{-1})	Neutron capture
B1	1.1501	0.9982	0.1766	186
B2	1.1501	0.7243	0.1914	134
B3	1.1501	0.6187	0.1958	134
B4	1.1501	0.6089	0.1982	141
B5	1.1501	0.5784	0.2017	144

Table4. The measured values of equivalent dose rate, cross section and neutron capture

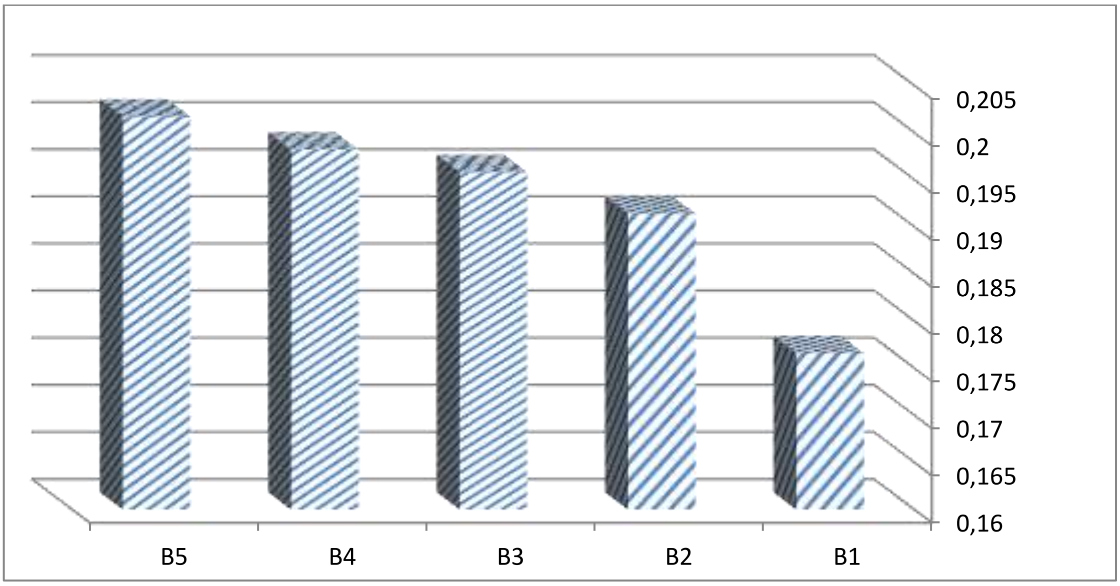

Fig1. The Cross Section of hybrid fiber heavyweight aggregate concretes

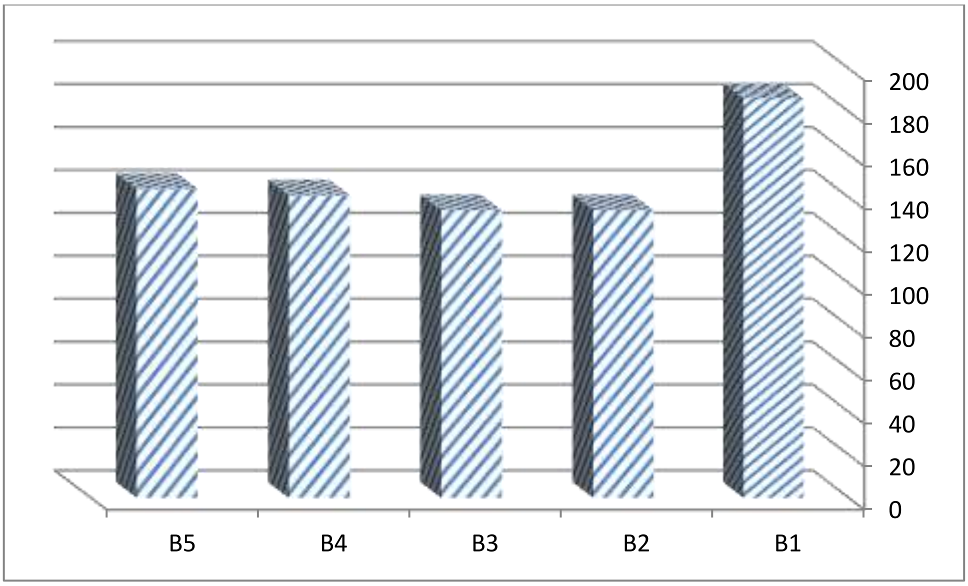

Fig2. The measured values of neutron capture of hybrid fiber heavyweight aggregate concretes

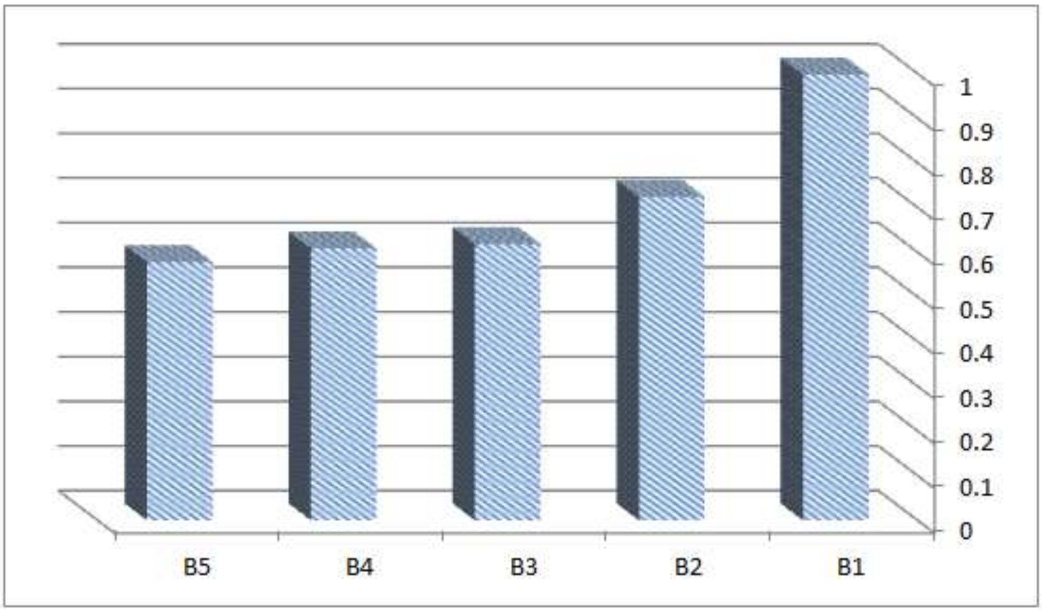

Fig.3. Absorbed dose by detector of hybrid fiber heavyweight aggregate concretes

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Conflict of Interest

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