ISSN 2229-5518

Improving Heavy Concrete Shielding Materials against Fast Neutron Radiation Leaks with Experimental and Monte Carlo Simulation (Geant4) Code

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Abstract— Biological shielding of nuclear reactor and diminishing the intricacy and cost of these installations are important interests in physic. In this study, we used galena minerals and barite for production of a hybrid fiber heavyweight aggregate concrete. Barite is an important chemical element for neutron absorption processes and galena minerals exist in many parts of world which was used in the concrete mix design. The cross section in matter and neutron capture explain 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 samples calculated by using Geant 4 Monte Carlo code. As a result, use of appropriate galena concentration and barite and use of monofilament polypropylene fiber with steel fiber can improve cross section value of hybrid fiber heavyweight aggregate concrete and enhance properties of neutron shielding.

Index Terms— Galena, barite, neutron cross section, Geant 4 Monte Carlo code, hybrid fiber heavyweight aggregate concrete, shielding

Introduction

Hybrid fiber heavyweight aggregate concrete can be used for many purposes but usually preferred as a radiation shielding material because of its low cost, good structure and easier to form in compound and appropriate as neutron shielding materials compared to other shielding materials. Y.Abdoullah et al. [1] investigated that mostly concretes are composites material consist of aggregate, sand, water and cement. Radiation shielding of nuclear reactor is an expensive and very complex process.

Pavlenko VI et al. [3] have studied that a nuclear reactor usually needs two shields; a shield to protect the walls of the reactor from radiation harm and at the same time reflect neutrons back into core; and a biological shield to protect people and the environment. The biological shield that composed of many centimeters of very high density concrete, decreases the rank of Gamma radiation and neutrons to certain dose limits. S.M.J Mortazavi et al. [4] reached that in nuclear reactors, neutron radiation is the most difficult to shield and hydrogen is the largest efficient element in decelerating (thermalizing) neutrons over the whole energy spectrum. Largest of the hydrogen in concrete normally display 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. [5] suggested that Boron is an influential chemical element for neutron absorption procedure. It has important interest in shielding technology because of flawless shielding characteristics of it.

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ISSN 2229-5518

Baştürk M et al. [6] have found that it is an influential absorber used in neutron shielding materials. There are 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. [12] investigated that concrete that 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/m^3) is greatly used for superficial and orthovoltage radiotherapy rooms [12].

Galena (PbS) is the main lead mineral [13]. Galena have two cerusssite ($PbCO_3$), plattenerite (PbO_2) and anglesite ($PbSO_4$). Galena is a considerably dense material, having a density of 7400-7600 kg/m^3, so it is closely as dense as iron. The chemical composition and physical properties of Galena are summarized in table 1.

TABLE1
PHYSICAL AND CHEMICAL COMPOSITION OF THE GALENA MINERAL USED IN THIS STUDY

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

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

TABLE 2
CHEMICAL COMPOSITION OF THE BARITE 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

In 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 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 of the samples via Geant4 Monte Carlo code. Cross section and neutron capture of our hybrid fiber heavyweight aggregate concretes is summarized in table 4.

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

2 MATERIAL AND METHODS

The starting materials were consisting of galena, barite, cement, water, plasticizer and many kind of fibers. Galena minerals were used for production of a heavy concrete. To be used as a shield in nuclear reactors, concrete must contain a large amount of water. Higher water content lead concrete to be more efficient than regular concrete. In this study 5 types of concrete mixes were produced. Concentration of galena, barite and fibers in concretes showed in table 3.

TABLE 3 A
THE CODE OF CONCRETES

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

Cross section of hybrid fiber heavyweight aggregate concretes are shown in fig.1.

TABLE 3 B
CONTENT OF COMPOSITION OF HYBRID FIBER HEAVYWEIGHT AGGREGATE CONCRETE IN 1000 DM^3

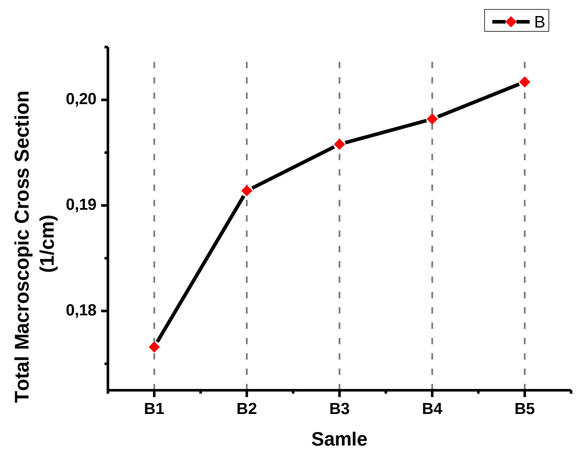

Fig1. The Cross Section of hybrid fiber heavyweight aggregate concretes

Neutron capture of hybrid fiber heavyweight aggregate concretes are shown in fig.2. Absorbed dose by detector of hybrid fiber heavyweight aggregate concretes is shown in fig.3. Radiation test was carried out by exposed to neutron source ^{241}Am-Be (number of events processed 1000000).

2.1 MONTE CARLO SIMULATION

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

3 RESULTS AND DISCUSSION

The cross section and neutron capture are influential factors to determine neutron shielding characteristics of sample. There is no simple scaling law for neutron linear attenuation coefficient Σ. But the cross section is described and denoted by Σ for neutron. The linear attenuation coefficient has units

ISSN 2229-5518

of inverse length, generally pointed out by cm^{-1}. The microscopic extent about 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 dose has been measured by a neutron detector. The cross section and neutron capture have been obtained from 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 detector of hybrid fiber heavyweight aggregate concretes. It is seen successfully that the neutron cross section are strongly dependent on the using of monofilament polypropylene fiber in the concretes and as can be seen from fig.1 that B5 sample have high cross section value and low absorbed dose rate.

TABLE4
THE MEASURED VALUES OF EQUIVALENT DOSE RATE, CROSS SECTION AND NEUTRON CAPTURE

Sample	Source Equivalent dose rate (μSv/h)	Absorbed dose by detector (μSv/h)	Cross section (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

So it has neutron shielding feature in compare to other samples. Also the measured values neutron capture by using Geant4 is shown in fig.2. As essentially indicated above, the using of monofilament polypropylene fiber effect on neutron shielding capability of matter. Thus, as can be seen from fig.1, fig.2 and fig.3 B5 is more effective shielding material because it has high cross section, high neutron capture values and low absorbed dose rate.

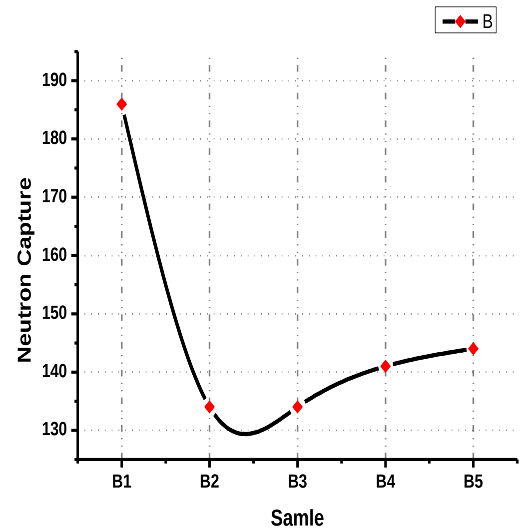

Fig2. The measured values of neutron captures of hybrid fiber heavyweight aggregate concretes

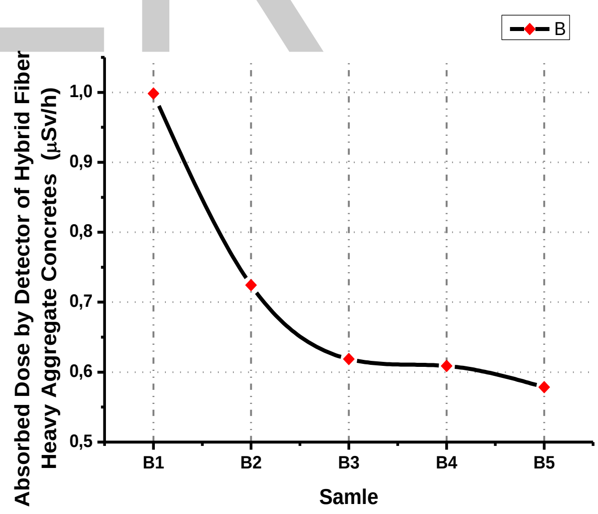

Fig.3. Absorbed dose by detector of hybrid fiber heavy aggregate concretes

4 CONCLUSIONS

We have investigated in present study, fast neutron shielding properties of galena (PbS), barite, and different percentage of galena with many kind fibers by using experiment and simulation process. In the results of this research have provided new comment about the cross section of fast neutron through materials including different percentage of galena, barite and many kind 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 moderator for nuclear reactors, in nuclear medicine departments and nuclear investigation centers, etc., to protect damages from neutron particle.

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