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Evaluation of the performance of peridotite aggregates for radiation shielding concrete

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ABSTRACT

Peridotite is a kind of material that is rich in crystal water. In this paper, peridotite is used as fine and coarse aggregates for radiation shielding concrete. The transmission data of different concrete thickness and different energy neutron are calculated using Monte-Carlo method. The neutron shielding performance of the peridotite concrete samples are tested using ^{241}Am-Be neutron source. The results show that the peridotite is an excellent neutron shielding material.

1. Introduction

Radiation shielding concrete (RSC) is used in nuclear power plants, health care facilities conducting radiation therapy, nuclear research facilities, and storage/transport casks for radioactive waste (Lee et al., 2013). In RSC mixtures, light atomic aggregates, such as materials containing hydrogen, are used to absorb neutrons. The content of crystal water or bound water in shielding concrete is one of the important factors affecting the shielding performance of concrete, because hydrogen occupies a large proportion in water. Thus, water proportions will affect the characteristics of radiation shielding mixture.

As for the position in concrete, water mainly exists in form of crystal water (which is contained in the solid constituent materials of concrete mix), bound water (which is contained in the hydration products of cement) and free water (which remains in the pore system of the cement–water paste acting as a source of reaction water during the hydration period). The crystal water and bound water are fixed in the concrete and cannot be lost in evaporation. Free water can diffuse through the concrete, and much of it will be lost in evaporation under the condition of high temperature or dryness (Kharita et al., 2010). Therefore, research on the crystal water content to make sure that the shielding concrete stays in long-term stability is particularly important.

The shielding properties of concrete may vary depending on the composite of the concrete. Aggregates occupy the largest proportion of concrete (about 70–80% of the total weight of normal concrete). The most common natural aggregates used in RSC are extracted from ores of high-density minerals, such as limonite, hematite, ilmenite, magnetite, and barite. For neutron ray shielding, the content of crystal water in the aggregate is generally required to be higher than 10% (ASTM C637–09, 2009) and the aggregate itself should possess thermal stability. Among the common used aggregates, only limonite meets the requirements, but it has poor thermal stability. This paper studies the neutron shielding performance of peridotite rock, which is rich in crystal water. The transmission data of different concrete thickness and different energy neutron are calculated using Monte-Carlo method. The neutron shielding performance of the peridotite concrete samples are tested using ^{241}Am-Be neutron source.

2. Material and methods

2.1. Material

Crystal water containing hydrogen in concrete can enhance the effect of shielding neutron, because such compound can capture neutron effectively and will not form secondary gamma ray. In this paper, peridotite rich in crystal water is chosen as the coarse and fine aggregates for concrete (from Liaoning province, PR China). The composition of peridotite aggregates and ordinary aggregates are shown in Table 1. It can be seen that the peridotite aggregates contain 12.95 wt% crystals water, and therefore can be used as concrete aggregate for neutron radiation shielding.

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Table 1
The composition of peridotite aggregates and ordinary aggregates.

Composition	Peridotite aggregate Content (Wt%)	Ordinary aggregate Content (Wt%)
SiO_2	39.4725	49.9250
MgO	38.7551	35.5823
Fe_2O_3	7.7312	9.4646
Al_2O_3	0.1568	0.3712
CaO	0.2575	0.4613
SO_3	0.0948	0.0663
MnO	0.1798	0.1369
P_2O_5	0.0614	–
Cr_2O_3	–	0.4447
WO_3	0.0302	0.0662
Co_2O_3	0.0262	0.413
ZnO	–	0.0295
NiO	0.0113	0.0362
Absorption water	0.1907	0.3496
Crystal water	12.9503	2.5286

2.2. Preparation of samples

The concrete drawn from the peridotite aggregates are used as samples in the experiment, and the concrete extracted from common widespread lime stones composed mainly of dolomite ($CaCO_3$, $MgCO_3$) are used as the referential samples. Table 2 shows the proportions of materials used in these concrete mixtures.

2.3. Experimental setup

The experimental process consists of two steps. In the first step, the neutron attenuation is simulated by Monte-Carlo method using MCNP simulation program. MCNP is a general-purpose Monte Carlo N–Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport, and has the capability of calculating the shielding performance of materials (Briesmeister, 2000), which is developed by Los Alamos National Laboratory, USA. The simulation setup is shown in Fig. 1. The radioactive source used during simulation is Am-Be neutron source, whose energy ranges from 10^{-6} to 20 MeV. The thickness of concrete samples ranges from 0 to 40 cm.

In the second step, the shielding properties of the concrete samples shown in Table 2 is studied in the field of neutron emitted by a ^{241}Am-Be source. Table 3 shows the parameters of the Am-Be neutron source.

The experimental setup is shown in Fig. 1. The distance between neutron source and concrete samples is 11 cm. The equivalent rate of neutron dose is measured with the neutron REM meter of CANBERRA Company.

The neutron transmission rate of each testing concrete samples is tested with ^{241}Am-Be neutron source. Firstly, the neutron equivalent dose rate with and without samples are tested, and then the neutron transmission ratio is calculated based on the neutron dose equivalent rate (El-Sayed Abdo, 2002; Fang, 1991).

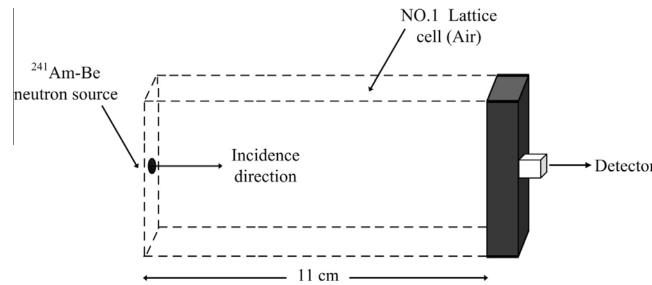

Fig. 1. Schematic draw of the setup of simulation and experiment.

Table 3
Parameters of ^{241}Am-Be neutron source.

Nuclide	Size	Date of production	The original neutron emission rate	The current neutron emission rate
Am-Be neutron source	Φ16 × 19 mm	1985.10	$1.0 \times 10^5\ s^{-1}$	$9.64 \times 10^4\ s^{-1}$

Table 4
Atom fraction values for concretes.

Peridotite concrete		Ordinary concrete	
Symbol	Fraction by weight (%)	Symbol	Fraction by weight (%)
Ca	0.13593	Ca	0.346714286
Mg	23.96586	Mg	21.75816
Fe	7.29967	Fe	6.78258
Mn	0.134556	Mn	0.104422535
Al	0.1503	Al	0.258670588
Si	17.89373	Si	23.03569333
K	0.143387	K	0.019997872
S	0.06212	S	0.04612
P	0.03157	Cr	0.246547826
W	0.035769	W	0.049648276
Co	0.021041	Co	0.03163253
Ni	0.017149	Ni	0.279502667
H	1.1267	H	0.280955556
O	48.98222	O	46.7516928
		Zn	0.007061728

3. Results

3.1. Simulation results

The neutron shielding properties of peridotite concretes with different thickness are simulated using the MCNP program under different neutron energy. In comparison, the properties of ordinary concretes are also tested. The simulation model is shown in Fig. 1. In the model, the isotropic point source is used. The incident direction

Table 2
Specifications of the fresh mixture of the prepared concrete.

Samples	The weights constituents (kg/m^3)				Dimensions (length*width*thickness) (cm)	Apparent density after 28 days dryness (kg/m^3)
	Cement	Water	Coarse aggregates	Fine aggregates		
Peridotite concrete	523	224	923	780	50 × 50 × 5 50 × 50 × 10 50 × 50 × 20	2450
Ordinary concrete	515	233	857	715	50 × 50 × 5 50 × 50 × 10 50 × 50 × 20	2320