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Study on mechanical and shielding properties of barite colemanite concrete

Study on mechanical and shielding properties of barite colemanite concrete

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Abstract. Natural and artificial mineral additives have been frequently used for improving the physical, mechanical and radiation shielding properties of concrete in recent years. However, it was found that the mechanical properties, including hardness, tensile strength and elongation at break, of these radiation shielding blocks were reduced with increasing of the amount of radiation shielding substance mixed in the radiation shielding In this study, the mechanical and shielding properties of concrete mix with barite and colemanite was use in order to produce optimize shielding for Boron Neutron Capture Therapy at the thermal column of Malaysia research reactor. The barite colemanite concrete formulations are based on ASTM standard and each sample was tested with both mechanical and radiation testing. In mechanical testing, the slump test, ultrasonic pulse velocity test and compressive strength test. For instance, the shielding properties of barite colemanite concrete was tested using neutron test using small angle neutron microscopy (SANS) and gamma test using ^{60}Co. The significance of mechanical and shielding test for barite colemanite concrete beneficial for the production of optimize use of barite and colemanite in concrete for high mechanical and high shielding properties for BNCT shielding purpose.

1. Introduction

In the application of nuclear technology, the protection of biological organisms from the adverse effects of radiation exposure is a basic requirement [1]. Many areas are now using nuclear technology in their application, such as nuclear research reactors, nuclear power plants, industrial inspections, and research facilities, which have put people and the atmosphere around the facilities at significant exposure from ionizing radiation. To ensure that people and the atmosphere surrounding nuclear facilities are protected from the adverse effects of ionizing radiation, sufficient safety is therefore necessary. Methods involving time, distance, and shielding [2] will prevent radiation exposure. Compared to others, shielding is the most effective form [3]. Commonly, concrete is widely used and known as radiation shielding for and nuclear facility [4]. Concrete is made up of cement, water, and aggregate (sand and rocks). Concrete is good for shielding gamma and thermalizing fast neutrons because of its density and content of hydrogenous material, which is water [5]. The concrete use in nuclear facility must be from Grade 40 and above and, their limitation is the concrete that is required has higher thickness to ensure that the nuclear facility is safe to use, as the cost of concrete is much less than lead. Lead proved to have greater photon absorption but less effective in term of weight, cost and mobility. In this research, the BNCT research facility is developed by having minor modification at thermal column and with portable shielding. Therefore, the shielding must be designed with effective absorption cross section, cost and weight. In conjunction, the idea of this research to improve the mix concrete capability by using the barite (good for gamma shielding) and colemanite (good for neutron shielding) with high mechanical strength. Previous research shows that the barite colemanite concrete mix can be used for X-ray facility bunker but not nuclear facility due to mechanical strength problem [6]. Thus, this research will improve and fulfilled this gap to ensure the barite colemanite concrete can be used as a shielding in nuclear facility.

2. Materials and methods

In this research, various design mixtures will be prepared based on the Department of Environmental (DOE) method of barite colemanite concrete. The mixture will be designed to achieve at least grade 40 concrete and has a density of more than 3.5 g/cm^3. The procedure for conducting the test cube samples is the same as other tests of concrete mixing. All of the materials, which are mixed into the concrete, namely Portland cement, water, sand, plasticizer, barite, and colemanite, will firstly be weighed. Next, all of the materials are mixed inside the rotary cement concrete mixer. To determine whether the target slump is reached, a slump test will be performed as per [7]. Then, the concrete mixture will be poured into several cube molds of 15 cm in dimensions. The concrete will be allowed to rest for 24 hours. After 24 hours, the concrete will be taken out of the mold and cured inside a water tank for 28 days. During the preparation of the samples, the concrete mixture will be going through the slump test to assess the consistency of the fresh concrete. Next, after 28 days of curing, the barite colemanite concrete samples will be tested in terms of its mechanical and radiation shielding capability. The concrete samples will be going through various tests, namely for mechanical properties testing and shielding properties testing.

2.1 Mechanical properties testing

2.1.1 Slump test. The test will be carried out following the ASTM C143. The steel slump cone will be placed on a solid, impermeable, and level base surface. Next, fresh concrete will be filled into the slump cone in three equal layers. Each layer is rodded twenty-five (25) times to ensure compaction. The third layer will be finished off level with the top of the cone. Then, the cone will be carefully lifted up, leaving a heap of concrete that slump slightly. The slump cone will be placed on the base to act as a reference, and the difference in the level between the top of the cone and the top of the concrete is measured and recorded to the nearest 10 mm to analyze the slump of the concrete. Illustration of the concrete slump test is shown in Figure1[7].

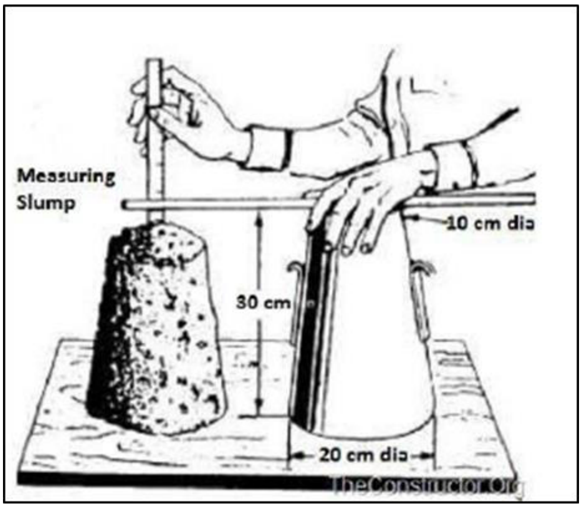

Figure 1. Slump test illustration[7].

2.1.2 Ultrasonic pulse velocity test. Ultrasonic pulse velocity test is an in-situ NDT method to evaluate the durability of the concrete. The evaluation will be carried out based on the correlation between time of propagation or velocity longitudinal ultrasonic waves in the concrete. Measurements are performed by the surface scanning with a fixed base. Ultrasonic pulse velocity testing equipment included a pulse generation circuit, consisting of an electronic circuit for generating pulses and a transducer for transforming electronic pulse into a mechanical pulse having an oscillation frequency in a range of 40 kHz to 50 kHz, and a pulse reception circuit that received the signal. The procedure is employed to perform an ultrasonic velocity test on the concrete [8]. The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks, and segregation, etc. can be assessed using the guidelines shown in Table 1, which have been evolved for characterizing the quality of concrete in structures in term of the ultrasonic pulse velocity.

Table 1. Guidelines for characterizing the quality of concrete structure in term of ultrasonic pulse velocity [8].

Pulse Velocity (km/s)	Concrete Quality (Grading)
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

2.1.3. Compressive strength test. The compressive strength test is important to determine whether the concrete mixture meet the target strength or not. The compressive strength test will be conducted on the hardened concrete samples [9]. This test also provides an idea about all the characteristics of the concrete. By this test, one may judge whether concreting had been done properly or not. Concrete compressive strength for general construction varies from 15 MPa (2200 psi) to 30 MPa (4400 psi) and higher in commercial and industrial structures. The compressive strength of concrete depends on several factors such as water-cement ratio, cement strength, quality of concrete material, and quality control during the production of the concrete, etc. The test of compressive strength can be carried out either on cube or cylinder concrete samples as display on Figure 2. In this research, the cube concrete samples will be used to test its compressive strength. These specimens will be tested by a compression testing machine after 28 days of curing [9]. The load is applied gradually at the rate of 140 kg/cm^2 per minute until the specimens fail while the load at the failure is divided by area of the specimens to get the compressive strength of the concrete.

$$Compressive\ strength\ (grade) = \frac{Compressive\ force(kN)}{Surface\ area(mm^2)} \quad (1)$$

Figure 2. Compressive strength test.

2.2. Shielding properties

2.2.1. Neutron scattering test. Neutron scattering test is performed after the sample hardened in 28 days from mixing. The concrete samples are placed in the front of the neutron beam at the small angle neutron scattering (SANS) facility at Reactor RTP and aligned at a 180° with the collimator. A neutron survey meter as shown in Figure 3 below is placed in after the concrete sample to obtain radiation readings transmitted after the sample. Each sample from A to E is shot with the beam and the reading of the survey meter was recorded. Readings of the survey meter without the sample in placed is also recorded to get the bare readings. In this test, the reactor power was 750kW with background of 692.57 µSv/hr.

Figure 3. Neutron scattering test.

2.2.2. Gamma transmission testing. The radioactive source used in this experiment was ^{60}Co with an activity of 111 MBq. Geiger Mueller (GM) detector will be used to measure the intensities of gamma radiation as show on Figure 4. The attenuation coefficient for gamma radiation of ^{60}Co is calculated using Equation 2. The total mass attenuation coefficients, μm is shown in Equation 2 [10]:

$$\frac{\mu m}{\rho} = \frac{\frac{1}{t}\ln\left(\frac{I_0}{I_d}\right)}{\rho} cm^2 g^{-1} \tag{2}$$

where ρ is the density of the specimen. In this test, the counts of I_0 and I_d will be measured on 15 cm before and after cubic barite colemanite concrete samples respectively. All of the samples will be tested with the same experimental set up and environmental conditions to avoid any inconsistency. A digital counter is used to measure the count of the incident gamma-rays, I_0 applied perpendicularly without the barite colemanite concrete sample. Next, the intensities of gamma-rays, I_d passed through the barite colemanite concrete samples will be measured [10].

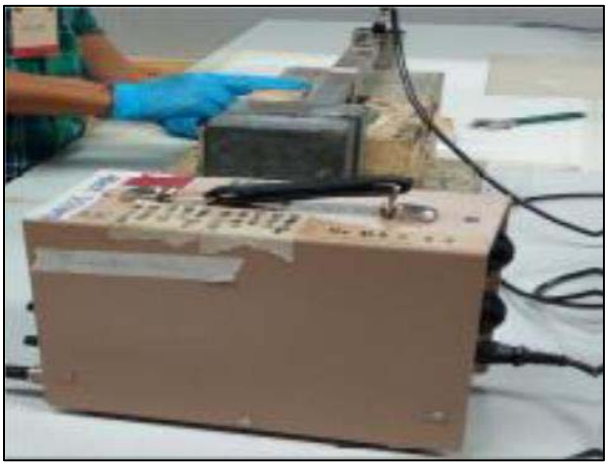

Figure 4. Gamma emission test.

3. Results and discussion

Table 2 shows the mixture percentage of the barite colemanite concrete based on the calculation from DOE. The calculation shows the five promising mixture formula for barite colemanite concrete based on Grade 40.

Table 2 The mixture percentage of the barite colemanite concrete samples.

	Mixture (%)				
Material	A	B	C	D	E
Cement	12.87	12.39	18.74	18.74	20.18
Water	9.94	8.17	7.5	6.88	4.65
Sand	18.71	20.28	25	25	24.71
Colemanite	11.7	11.27	1.25	1.88	1.85
Barite	46.78	45.07	46.5	46.5	46.95
Plasticizer	0	2.82	1	1	1.65

3.1. *Shielding Properties*

3.1.2. Effects of barite and colemanite in mix concrete on neutron. Table 3 and Figure 5 show the percentage of neutron absorbed and average equivalent neutron radiation on the concrete samples. The results showed that the highest amount of absorption of neutron radiation is from sample that consists of 46.95% barite and 1.85% of colemanite (Sample E), while the sample that absorbed the least amount of neutron is from sample which consists of 46.5% of barite and 1.25% of colemanite (Sample C). Sample E also shows lowest average equivalent neutron radiation detected show a good absorbent for neutron compared to other samples. This explains that the higher the percentage of neutron radiation being absorbed, the lower the average equivalent neutron detected. The results also concluded that the 46.95% barite and 1.85% of colemanite is the optimum amount to be added in the concrete mixture to achieve highest neutron absorption.

Table 3. Average data of neutron scattered percentage by barite colemanite samples.

Sample	Neutron Scattered (%)
A	95.85
B	96.22
C	89.91
D	96.41
E	98.88

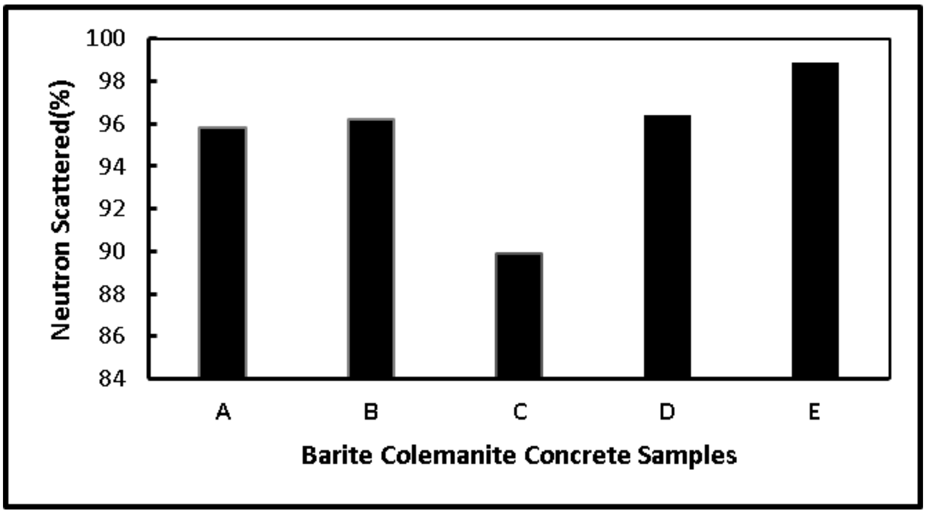

Figure 5. The neutron scattered percentage by barite colemanite samples.

3.1.3. Effects of barite and colemanite in mix concrete on gamma. Table 4 and Figure 6 shows the amount of gamma absorbed and gamma count rate of detector. Concrete sample D which consisted of 46.5% of barite and 1.88% of colemanite addition shows highest amount of gamma adsorbed with 75.18%. This explains that the more the amount of gamma radiation absorbed in the concrete mixture, the lower amount of gamma radiation pass through the concrete. The gamma count rate detected strengthens the finding, in which concrete Sample A shows the minimum amount of count rate detected. The addition of colemanite does not really improve the gamma radiation absorption as the Sample A have more than 10% colemanite on it.

Table 4. Average data of gamma absorption percentage by barite colemanite samples.

Sample	Gamma Absorbed (%)
A	71.8
B	73.31
C	75.03
D	75.18
E	75.15

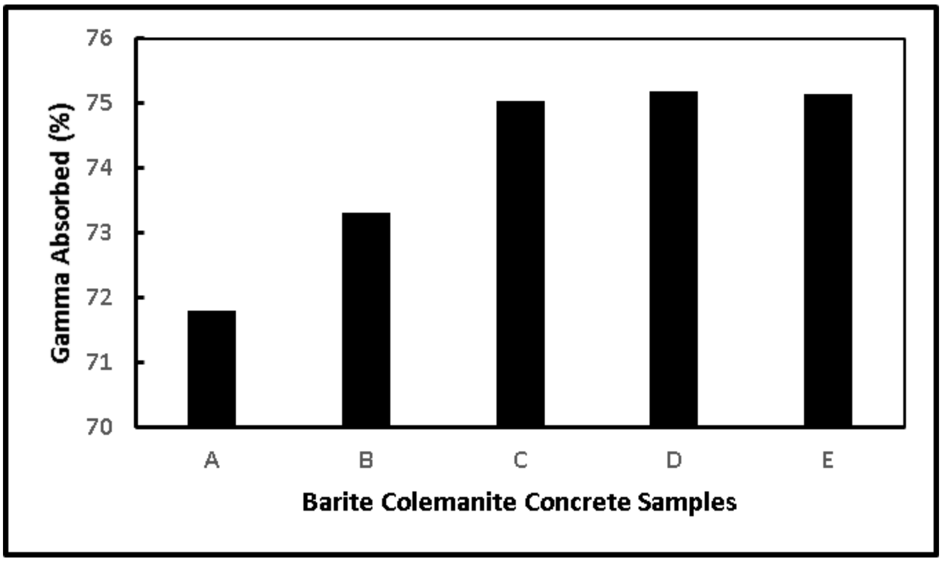

Figure 6. The gamma absorption percentage by barite colemanite samples

3.2. Mechanical properties

The mechanical properties of the barite colemanite concrete samples were tested using the three standard testing methods, namely the ultrasonic pulse velocity test, slump test, and compressive strength test. Table 5 shows the mechanical properties of barite colemanite concrete design. Based on the results shown in Table 5, the average pulse velocity for the design mix barite colemanite was 3.77 km/s. It shows that the concrete quality for barite colemanite was excellent based on the standard guidelines. However, the slump test for barite colemanite shows that Sample A has a high degree of workability compared to other samples. In order to achieve Grade 40, the standard slump test of the concrete produce must be between 30mm-60mm. In terms of compressive strength test for concrete samples of barite, colemanite shows that only one sample manage to achieve higher than Grade 40 which is Samples E that consist of 46.95% barite and 1.85% of colemanite. This mechanical property testing proved that to produce a good concrete mix higher than Grade 40, the design must pass all those testing and the standard guideline. Based on this research, the performance of the Sample E barite colemanite concrete for both shielding and mechanical properties has met the minimum requirements such as concrete quality, concrete density, and concrete strength.

Table 5. Mechanical properties testing result for barite colemanite samples.

Sample	Slump Test (mm)	Pulse velocity(km/s)	Compressive Strength Test (N/mm^2)
A	75	3.48	0
B	33	3.62	33
C	63	4..11	32
D	40	3.89	32
E	36	3.76	42

4. Conclusion

This study has demonstrated that varying the ratios of colemanite in the barite concrete mixture has different reaction towards neutron and gamma radiation absorption. In addition, the varying ratio of colemanite shows higher impact on the mechanical properties of the concrete mix design. Based on this research, only one samples succeeded to meet the minimum requirements such as concrete quality, concrete density, and concrete strength and good shielding properties for both neutron and gamma. 46.95% barite and 1.85% of colemanite are recommended to be considered to add on concrete for nuclear facility development.

5. References

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