Measurement of γ-Ray Attenuation Coefficient for Concrete with Different Aggregates

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1. Introduction

The demand of radiation shielding material for a safe transport and storage of radioactive materials increases rapidly with the commencement of the medium and low-level radioactive waste disposal facility. It is because radioactive materials from a nuclear reactor, spent nuclear fuels, fission products, and many industrial application of radiation influences on environment over a long period by releasing gamma-ray and neutron continuously [1]. Typical radiation shielding materials are lead, boron, iron, water, heavy-weight concrete, etc. In heavy-weight concrete, oxidizing slag from an electric arc furnace, magnetite and barite are used as an aggregate. The radiation shielding rate of the heavy-weight concrete which used oxidizing slag was studied [2]. In this work, we used different aggregates in a concrete to examine their effect on gamma-ray shielding. In addition, attenuation coefficient has been evaluated using a gamma-ray measuring system. The attenuation coefficient represents the amount of attenuated radiation by the thickness of a given sample material [3]. In this study, in order to calculate an accurate attenuation coefficient, radiation transmission rates were measured according to the thickness of concrete samples which included different aggregates.

2. Experiment set up

2.1 Preparation of concrete samples

A concrete sample was composed of cement, fine aggregate and coarse aggregate. Typical Portland cement which had the density of 3.15 g/cm^3 was used as a binder for manufacturing concrete samples. In order to compare a high-weight concrete with a normal concrete, general aggregates of sand and gravel was also used as reference. Two different sizes of oxidizing slags with average diameters of 2.5 mm and 20 mm were used as high weight aggregates. In addition, natural high weigh aggregate of iron ore with 10 mm in diameter was also used. The property of materials used in this work is presented in Table 1. Concrete sample manufacturing condition with different aggregates are summarized in Table 2.

Table I. Material property

Type		Density (g/cm^3)	Diameter (mm)
Binder	Cement (C)	3.15	0.01 - 0.012
Reference Aggregate	Sand (S)	2.6	1.2
	Gravel (G)	2.65	20
High-Weight Aggregate	Oxidizing Slag Sand (OSS)	3.77	2.5
	Oxidizing Slag Gravel (OSG)	3.62	20
	Iron Ore (IO)	3.98	10

Table II. Concrete mixing conditions

No	Type		Unit Weight(kg/m^3)			
	F.A	C.A	Water	Cement	F.A	C.A
1	S	G	175	350	889	906
2	S	OSG			889	1238
3	IO	G			1361	906
4	IO	OSS			1361	1289
5	OSS	OSG			1289	1238

*F.A = Fine Aggregate, C.A = Coarse Aggregate

2.2 Gamma-ray shielding experiment

The basic equation of transmission rate is (1). A narrow beam of gamma-ray with an incident intensity, I_0, penetrating a certain thickness of concrete sample. According to the attenuation coefficient, μ, the final intensity, I, is measured by a NaI(Tl) detector. In order to obtain the quantitative transmission rate for gamma-ray, we installed the measuring equipment as shown in Figure 1. We designed a collimator with lead which prevents radiation scattering and makes one directional radiation. The collimator has the inner diameter of 5 mm and the outer diameter of 25 mm, respectively. The thickness of the collimator is 40 mm, 25 mm. The maximum thickness of concrete sample is 50 mm which corresponds the distance between the detector and the collimator. As a γ-ray source, Cs-137 with 0.662 MeV was used. During the γ-ray measurement, the applied voltage was 800 V in the detector. The measurement time was fixed at 600 s for the whole experiment and three experiments were repeated for the same concrete sample. The attenuation coefficient, μ, was determined by exponential fitting using the transmission rate as follows:

$$\text{Transmission rate (T)} = I/I_0 = e^{-\mu t} \qquad (1)$$

I= Intensity after shielding
I_0 = Incident intensity
μ = Attenuation coefficient
t = Shielding material thickness

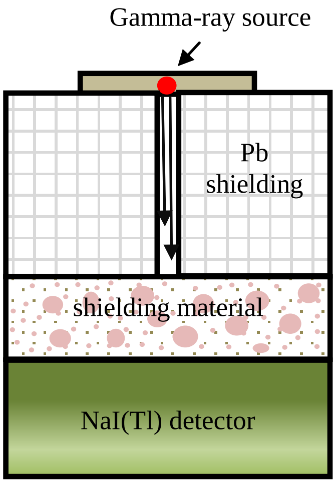

Fig 1. Measurements device of concrete shielding for the gamma-ray transmission with thickness

3. Result and discussions

According to the change of aggregate, the attenuation coefficient of gamma-ray was measured by using the basic expression formula of (1).

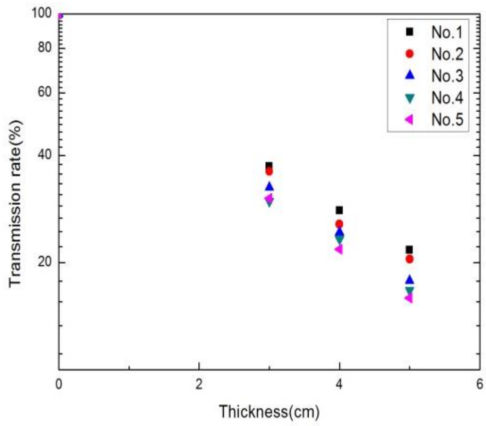

Fig 2. Transmission rate graph of gamma-ray for concrete with thickness and aggregate

Fig. 2 is the shielding experiment result graph for gamma ray irradiation. The transmission rates are presented in Tabe3 for performance of shielding material. The lower the value of transmission rate is excellent shielding performance. In this work, aggregate rate and unit weight into the concrete increase, and it was confirmed that the transmission rate was lowered.

Table III. Transmission rate of gamma ray with concrete thickness

No.	Thickness	Transmission rate (%)
1	30 mm	37.28
	40 mm	28.07
	50 mm	21.74
2	30 mm	36.08
	40 mm	25.68
	50 mm	20.49
3	30 mm	32.59
	40 mm	24.36
	50 mm	17.82
4	30 mm	29.79
	40 mm	23.28
	50 mm	16.74
5	30 mm	30.32
	40 mm	21.84
	50 mm	15.93

Table 3 and Fig. 3 show the transmission rate of gamma ray and attenuation coefficient with concrete thickness. In order to measure the attenuation coefficient, transmission rate was more quantitatively measured with increasing thickness of concrete. The experiment result of No.1 is higher than experiment results of reference [4]. It is because of both sample and aggregate have similar size, and many of aggregate is gathered at direction of radiation due to interact with radiation.

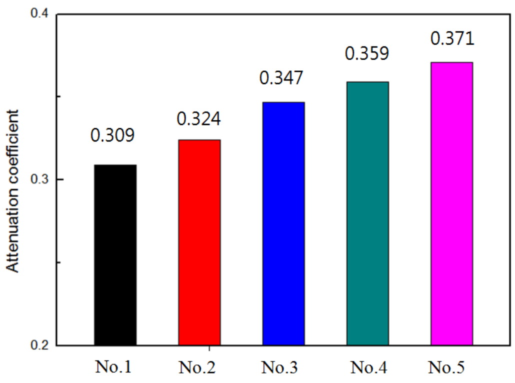

Fig 3. Attenuation coefficient with concrete mixing conditions

The transmission rate is reduced by increasing the unit weight, and the attenuation coefficient increase. However, in the No.4, the unit weight with increasing did not come out at low transmission rate. The unit weights of No.4 and No.5 have a similar value, but there is different result for the transmission rate and attenuation coefficients. No.5 is lager value than No.4 for attenuation coefficient. Shielding performance is thought to affect the high weight aggregate than unit weigh. The IO is lower specific gravity than the OSS, it is because of the high density including metal property relatively. All value of attenuation coefficient is not large difference with increase in unit weight. It is because of the limitation of gamma irradiation experiment. In order to obtain accurate data, the repetitive test measurement is necessary

3. Conclusions

In this study, shielding performance of concrete was confirmed to increase, according to the increasing in unit weight and aggregate. However, Iron ore is the density greater than oxidizing slag gravel, but attenuation coefficient is lower than including oxidizing slag gravel. Shielding performance improvement is expected to effect on the increasing high-weight aggregate rather than unit weigh and it is consider that additional research is needed for mixing condition of aggregates. Both size of coarse aggregate and experiment sample is a few cm thicknesses. Therefore, location of shielding material including metal component in sample is important, according to direction of radiation. Additionally, to know the reliability of the shielding experiments that is conducted for element material and compare with reference date.

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