Study on Basic Characteristics for the Development of Radiation Shielding High-Weight Concrete

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1. Introduction

A safe and sustainable nuclear power which provides a stable base load power is required to avoid a serious electric power shortage like the blackout. In addition, the disposal of Gori nuclear power plant and new construction of nuclear power plants are issued recently. Nuclear power accounts for 37.5% in 2016 and it will grow to be 50% in 2024. Therefore, it is planned to build a power plant more than 6 units [1]. Although the demand of a nuclear power plant is going to increase, the attention for radiation shielding is relatively in a low level. Concrete is one of the excellent and widely used shielding materials. Since the radiation shielding of a given material is proportional to density and thickness, a high-weight concrete with high-weight aggregate which is higher than normal concrete is used for radiation shielding. However, there are a few studies and references about radiation shielding concrete [2, 3]. Therefore, it is required to find a high-weight aggregate. The purpose of this paper is the development of a high-weight concrete to improve radiation shielding capability.

2. Material and Mixing design

In this section materials and mixing design for the development of a high-weigh concrete are described.

2.1 Material

Materials used this study are ordinary Portland cement, normal aggregates and high weight aggregates as being produced in domestic. Two type of high-weight aggregates such as natural and by-product high weight aggregates are used. By-product high weight aggregate is an oxidizing slag from an electric arc furnace process, and natural high weight aggregate is iron ore. Characteristics of materials using the study are shown in Table 1.

2.2 Mixing design and unit weight of concrete

In order to evaluate the radiation shielding performance of concreate with different aggregates, various combination of fine aggregate and coarse aggregate has been studied. An admixture was used at 0.8wt% of cement. The volume ratio of water to binder and fine aggregate and coarse aggregate were fixed at 5:5. The unit weight of concrete according to mixing condition is shown in Table 2.

Table I: Material property

Type		Density (g/cm^3)	Diameter (mm)	Absorption (%)
Binder	Cement (C)	3.15	0.01 -0.012	-
Reference Aggregate	Sand (S)	2.6	1.2	1.0
	Gravel (G)	2.65	20	1.0
High Weight Aggregate	By-Product Sand (BPS)	3.77	2.5	-
	By-Product Gravel (BPG)	3.62	20	1.2
	Natural High-Weight Sand (JS)	3.98	10	2.6
	Natural High-Weight Gravel (JG)	3.6	12	1.0

Table II: Unit weight of concrete according to mixing condition

No	Type		Unit Weight(kg/m^3)				unit weight (kg/m^3)
	F.A	C.A	Water	Cement	F.A	C.A	
1	S	G	175	350	889	906	2320
2	JS	G			1361	906	2792
3	BPS	G			1289	906	2720
4	S	JG			889	1231	2645
5	S	BPG			889	1238	2652
6	BPS	BPG			1289	1238	3052
7	BPS	JG			1289	1231	3045
8	JS	BPG			1361	1238	3124
9	JS	JG			1361	1231	3117
10	JS	BPS			1361	1289	3175

*F.A=Fine Aggregate, C.A=Coarse Aggregate, W=Water, C=cement

Experiments were conducted on γ-ray transmission rate, slump, air containing, and compressive strength. Except for γ-ray transmission rate, KS test method for concrete was used [4]. A laboratory equipment for gamma-ray shielding test was composed of the Canberra Model 727 Lead Shield with NaI(Tl) detector, ^{137}Cs source, and pierced Pb block for measuring one directional radiation.

Concrete samples for gamma-rays transmission experiment were prepared as Φ50*100mm, then, it cut with 30, 40, 50 mm. The unit weight of concrete is average value of three samples with different thickness.

3. Result and Discussion

3.1 Chemical composition of aggregates

Chemical composition of reference and high weight aggregates used in this study is shown in Table 3. The density of high weight aggregate was higher than that of reference aggregate in Table 1. In the chemical composition analysis, it is believed that Fe_2O_3 of high weight aggregate is major factor to increase density. Also, the chemical composition of aggregated is also important in addition to the unit weight. The composition of CaO in by-product aggregate is higher than that in natural high weight aggregate, while MgO in by-product is lower than that in natural high weight aggregate.

Table III: Chemical composition of aggregates

Type	Chemical composition (%)						
	Al_2O_3	SiO_2	SO_3	CaO	Fe_2O_3	MgO	Etc
S	5.75	86.17	0.02	0.47	0.54	0.18	6.87
G	12.97	66.07	0.15	5.6	3.19	2.17	9.85
BPS	4.04	26.21	0.11	28.43	33.14	7.86	0.21
BPG	7.71	23.97	0.57	31.69	27.83	8.01	0.22
JS	5.39	12.97	0.24	6.28	45.57	23.36	0.19
JG	7.99	36.93	0.04	15.40	13.11	26.28	0.25

3.2 Effect of unit weight on γ-ray shielding

The variation of radiation shielding rate for concrete with the thickness of 40 mm is presented in Fig 1. All of concrete replacing high-weight aggregate show higher radiation shielding rate than normal concrete. Generally, the radiation shielding rate is improved in a high unit weight. In the case of using by-product aggregate to fine and coarse aggregates achieved the highest radiation shielding rate.

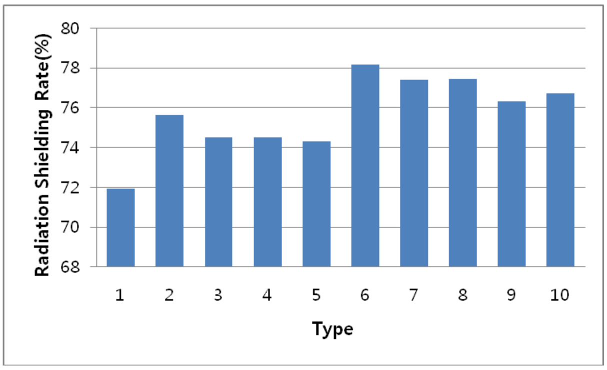

Fig 1. Radiation shielding rate of concrete with 40 mm in different aggregates.

3.3 Effect of thickness on γ-ray shielding

Fig 2 shows the result of radiation shielding rate in accordance with thickness of concrete. By increasing the thickness of concrete, it is confirmed that radiation shielding rate increases. As thickness increases by 10 mm, radiation shielding rate increases 6~9% on average.

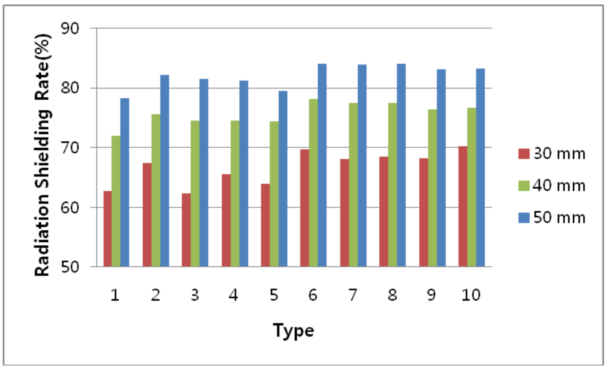

Fig 2. Radiation shielding rate according to thickness in different aggregates.

3.3 Characteristic of concrete

Design strength and the property are essential elements to evaluate concrete. Test results of compressive strength and property are presented in Table 4. All of concrete replacing high weight aggregate are higher compressive strength than reference concrete. It is considered that adhesion between paste and a rough surface of high weight aggregate increases and bonding force between particles grow bigger [5]. Although slump and air contents are reduced in the natural high weight aggregate, they are slightly increased in the by-product high weight aggregate. It can be explained by relatively high absorption rate of the natural high weight aggregate. Therefore, using additional admixtures is needed to make slump and air content adjust to KS standards [4].

Table VI: Result of compressive strength, slump, and air contents

No	Compressive Strength (MPa)				Slump (mm)	Air (%)
	1D	3D	7D	28D		
1	4.55	17.4	23.7	35.1	300	1.5
2	14.05	27	34.45	43.7	30	0.5
3	8.5	20.2	24.9	35.05	300	2
4	9.1	23.45	35.3	49.1	30	0
5	7.95	24.65	33.25	48.85	215	3
6	9.8	25.45	38.05	51.23	185	1.4
7	8.5	20	28.3	38.56	30	2
8	14.2	32.6	46.9	55.23	160	2.1
9	13.15	29	41.6	53.68	30	0
10	13.7	33.45	45.3	56.02	30	3.5

4. Conclusions

The radiation shielding rate of high-weight concrete is higher than that of reference concrete. It is confirmed that the density of aggregate and the unit weight of concreate is proportional to the radiation shielding rate. In addition, the chemical composition of aggregate has also has an important effect on γ-ray shielding. Therefore, high weight aggregates of higher density are essentially required to improve radiation shielding capability. The compressive strength of a high weight concrete is better than that of reference concrete. Slump and air contents, however, are slightly increased with by-product aggregates. Such problem is expected to be solved by the development of concrete mixing technology.

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