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Assessment of gamma radiation shielding properties of concrete containers containing recycled coarse aggregates

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HIGHLIGHTS

- Linear attenuation coefficient, μ, of concrete was investigated.
- The μ values of RCA are slightly lower than NCA.
- Surface dose rate of transportable concrete containers was examined.
- Maximum surface dose rate of the concrete containers was turned out below 2 mSv/h.

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ABSTRACT

This paper presents an assessment of gamma radiation shielding performance, specifically in terms of surface dose rate, of concrete containing virgin and recycled coarse aggregates (RCA) to be used for a transportable concrete container for radioactive waste. In order to evaluate radiation shielding performance of the transportable concrete container a numerical simulation method is performed using Monte Carlo N-particle version 6.1 (MCNP6.1). Prior to evaluating radiation shielding performance of the transportable concrete containers, radiation shielding properties of four different concrete mixtures which have two different compressive strengths, 40 and 70 MPa, containing natural coarse aggregate (NCA) and recycled coarse aggregate (RCA), respectively, are assessed using experimental and numerical simulation methods in terms of linear attenuation coefficient (μ) to verify the reliability of the numerical simulation method. Density, compressive strength, and static modulus of elasticity tests are conducted to determine the parameters for transportable concrete container design. Based on the physical properties of concrete a transportable concrete container is designed. In order to assess the radiation shielding with respect to the maximum surface dose rate of the concrete containers, three different radioactive wastes are assumed to be loaded in the containers with metal drums and radiation shielding analysis is carried out using MCNP6 simulation code for the four different concrete containers, comparing with the existing carbon steel container. It was found that the results from numerical simulation are in good agreement with the experimentally determined results. In terms of the maximum surface dose rate, all concrete containers showed considerably lower surface dose rate than the existing carbon steel container.

1. Introduction

One of the problems facing in nuclear industry is the accumulation of radioactive waste from decommissioned nuclear power plants; this is especially true for the countries with no reprocessing of the used fuels and with limited radioactive waste disposal space. In order to be properly stored, this radioactive waste needs to be transported in specific containers. The ideal container for radioactive waste should meet rigorous criteria and the level of performance when handling and transporting. According to the International Atomic Energy Agency (IAEA) regulations, there are two primary considerations for the safe transport of radioactive materials contained in any packaging [1]. The first consideration is radiation protection in terms of surface dose rate limit and the

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second is physical soundness with respect to dropping and stacking resistances.

Nowadays, concrete is widely used as a shielding material against radiation of strong penetrating power due to its effective shielding characteristics, relatively low cost, and sufficiently long durability. For these reasons, many studies have been conducted in assessing radiation shielding characteristics of hardened cement paste using various supplementary cementitious materials such as ground granulated blast-furnace slag, fly ash, and silica fume and so on and of concrete using different kinds of aggregates for several decades [2–7]. Meanwhile, one of the most important issues in construction industry is the depletion of virgin aggregate and increase of concrete demolition waste. As part of viable solution for those, use of recycled aggregates from concrete demolition waste was suggested. In this regard, many studies on mechanical properties and durable performance of concrete containing recycled aggregates have been conducted and shown a significant possibility to be used as structural materials [8–14]. However, there are very few studies dealing with radiation shielding properties of concrete containing recycled coarse aggregates (RCA).

The purpose of this study is to present the radiation shielding properties of transportable concrete containers made with RCA and intended for transport of radioactive waste from decommissioned nuclear power plants. This is done using a numerical simulation code. Prior to evaluating the radiation shielding performance of the transportable concrete containers, the physical properties of hardened concrete samples such as density, compressive strength, and static modulus of elasticity for two different compressive strengths, 40 and 70 MPa, each made with 0% (considered the control sample) or 100% of recycled coarse aggregates are investigated. In total, radiation shielding performance of four different concrete mixtures is evaluated using experimental and numerical simulation methods.

Based on the physical properties of the concretes, a transportable concrete container for radioactive waste was designed with respect to reinforcement based on the American Association of State Highway and Transportation Officials Load and Resistance Factor Design (AASHTO LRFD) for culverts [15]. Furthermore, in order to assess the radiation shielding with respect to the maximum surface dose rate of the transportable concrete containers three different radioactive wastes (a low and two intermediate levels), specially for gamma rays, are adopted to be loaded in the containers with metal drums and radiation shielding analysis is carried out using MCNP6 simulation code for the four different concrete containers, comparing with the existing carbon steel container.

2. Materials

Concrete with two different compressive strengths, 40 and 70 MPa are analyzed in this study. For each concrete mixture, 100% of crushed natural granite coarse aggregate (NCA) and recycled coarse aggregate (RCA), which is obtained from demolition buildings meeting Korean Standard F 2573 (KS F 2573) [16] are used. The same type of sea sand is used as a fine aggregate (FA) for all samples. Table 1 summarizes the properties of NCA, RCA, and FA, including the contents of KS F 2573 for recycled coarse aggregates. Ordinary Portland cement (OPC) equivalent to KS L 5201 Type 1 [16], ground granulated blast furnace slag (GGBFS) produced in Gwangyang, South Korea, and silica fume (SF) manufactured in Canada are used as cementitious materials. Also polycarboxylate ether superplasticizer (SP) is added as an admixture. Table 2 shows chemical and physical properties of all of these materials except

Table 1
Properties of NCA (natural granite coarse aggregate), RCA (recycled coarse aggregate), and FA (fine aggregate).

	NCA	RCA	KS F 2573	FA
Max. size (mm)	19		–	5
OD density (g/cm^3)	2.62	2.49	Above 2.5	2.54
Absorption (%)	1.22	3.07	Below 3.0	1.44
Abrasion resistance (%)	17.4	25.9	Below 40	–
Soundness (%)	8.7	13.5	Below 12	4.1

Table 2
Chemical and physical properties of concrete mixture materials.

	Weight fraction (%)					
	OPC (Type1)	GGBFS	SF	XRF		
				FA	NCA	RCA
SiO_2	21.10	35.18	96.50	91.76	74.60	56.54
Fe_2O_3	2.90	2.85	0.09	0.39	1.89	6.75
CaO	62.50	36.75	0.2	2.31	4.14	12.56
Al_2O_3	6.10	17.23	0.25	4.17	11.60	14.29
MgO	2.20	2.43	0.55	0.71	0.55	2.25
Na_2O	–	2.97	0.25	0.16	1.60	1.67
K_2O	1.74	0.38	0.45	0.12	3.51	4.28
TiO_2	–	0.97	–	0.11	0.60	0.75
P_2O_5	–	0.22	–	0.16	0.17	0.13
MnO	–	0.37	–	–	0.12	0.31
SO_3	2.20	0.37	–	–	–	0.30
Others	–	0.27	0.29	0.11	0.10	0.16
LOI	1.07	0.32	1.42	–	–	–
SG*	3.15	2.85	2.25	–	–	–

* SG: Specific Gravity, OPC: Ordinary Portland Cement, GGBFS: Ground Granulated Blast Furnace Salg, SF: Silica Fume, FA: Fine Aggregate, NCA: Natural granite Coarse Aggregate, RCA: Recycled Coarse Aggregate.