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Effects of heavy weight waste glass recycled as fine aggregate on the mechanical properties of mortar specimens

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ABSTRACT

The quantities of heavy weight waste glass have increased over time due to rapid industrialization and changes in the quality of life. Moreover, most of this waste is not recycled. Concrete is the most widely used construction material, the huge amounts of natural resources are required to make concrete. Therefore, it is necessary to investigate the possibility of recycling of heavy weight waste glass as an ingredient in the manufacturing of concrete.

In this study, the suitability of heavy weight waste glass as a fine aggregate material is considered. The results of flow test, unit volume weight, radiation shielding performance, compressive strength, flexural strength, and micropore and macropore distribution of mortar are compared and evaluated. It was found that when the heavy weight waste glass substitution ratio increases, the fluidity, unit volume weight and radiation shielding performance also increase. However, the compressive and flexural strength of mortar gradually decrease with an increase in the substitution ratio of heavy weight waste glass. Moreover, the micro pore size distribution is significantly affected by the substitution of heavy weight waste glass.

1. Introduction

Concrete is one of the most widely used construction material in the world, and it is a fundamental material nearly all structures. The use of alternative aggregate is, however, urgently needed because aggregate shortages continue due to the exhaustion of natural aggregates and strict environmental restrictions placed on the construction industry. In addition, as industrialization is rapidly increasing and standards of living are changing, the quantities of industrial waste have also increased, rapidly. To deal with this situation, much attention has been paid to the development of many types of construction materials from industrial waste (Ahmed, 2014). Accordingly, several types of industrial waste are now used in the manufacturing of eco-friendly materials which replace the traditional construction materials. Among the various types of industrial waste, glass is considered the most suitable substitute as an aggregate due to its physical characteristics and chemical composition (Tan and Du, 2013; Shi and Zheng, 2007; Wang, 2009). Furthermore, earlier work has shown that recycled glass may be suitable for use in a wide range of applications including concrete, bricks and in road engineering project (Park et al., 2004; Disfani et al., 2011; Taha and Nounu, 2008; Loryuenyong et al., 2009).

Mehta and Monteiro reported that concrete can be efficiently used for radiation shielding purposes due to its good mechanical and radiation shielding properties (Mehta and Monteiro, 2014; Wang et al., 2001; Kim et al., 2012). This type of, concrete is then used as a structure to protect the human body from radiation. Most of the concrete used in radiation shielding involves heavy weight concrete. Heavy weight concrete is commonly defined as a concrete with a density higher than 2500 kg/m^3 which uses heavy weight aggregates such as barite or magnetite. However, this type of concrete is nearly impossible to produce in South Korea.

On the other hand, because CRT funnel televisions and monitors are being replaced with LCD panel, Korea's manufacturers have determined to stop producing CRT in televisions and monitors. However, the most of this outdated equipment is not recycled. It is well known that CRT glass (i.e., heavy weight waste glass) contains heavy metals, such as lead, iron and others. Accordingly, environmental concerns related to the disposal of discarded heavy weight waste glass in CRT have increased significantly (Poon, 2008). Technical treatment methods remain insufficient, and heavy weight waste glass has been illegally dumped or buried in landfills, leading to much environmental pollution. Therefore, it is important to investigate the recycling methods for heavy weight waste glass. For these reasons, many researchers have investigated the

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recycling of this type of waste glass (Lee, 2013; Ling and Poon, 2012; Castro and Brito, 2013). However, most studies used the waste glass removed the heavy metals in the form of crushed glass (Ling and Poon, 2012; Castro and Brito, 2013). Moreover, the replacement ratio of crushed heavy weight waste glass as a construction material is limited (Castro and Brito, 2013).

Therefore, we demonstrate the applicability of crushed heavy weight waste glass as a fine aggregate in shielding concrete based on previous research (Choi et al., 2015). At this time, heavy weight waste glass is simply crushed by jaw crushers, and waste glass is not treated by any chemical method. When heavy weight waste glass is replaced as a fine aggregate in mortar, the shielding performance of the mortar is improved due to the increase in the unit volume weight of the mortar. It is shown that the strength is affected according to mixing of the heavy weight waste glass.

Thus, in this paper, we investigate the effect of heavy weight waste glass on the mechanical properties of a mortar mix as a fine aggregate according to the substitution ratio. To investigate the mechanical properties of mortar, experimental tests of the fluidity, unit volume weight, and compressive and flexural strength were carried out. Also, to evaluate the pore structure of the mortar, the micropore and macropore distributions, the bulk density and porosity were estimated. The relationship between the mortar of unit volume weight and the radiation shielding performance was also compared.

2. Investigation method of radiation shielding concrete

The definition of radiation shielding concrete is not clear; however, such materials are useful for protecting against radioactive emissions in nuclear power plants (Mehta and Monteiro, 2014; Lee et al., 2016; Neville, 1981), medical units, and other structures where radiation shielding is required (Yang and Moon, 2012). A reduction in the thickness of a shielding member is accomplished due to the use of heavy weight concrete (Mehta and Monteiro, 2014). Heavy weight concrete is generally produced by using a heavy natural aggregate such as barite or magnetite. The unit volume weights of these aggregates are in the range of 3450–3760 kg/m^3 (Mehta and Monteiro, 2014), which is approximately 50 percent higher than that of concrete containing normal weight aggregates. Previous studies have shown that aggregates with a density higher than 3000 kg/m^3 can be considered as heavy weight aggregates for the production of heavy weight concrete (Maslehuddin et al., 2013).

In order to investigate the shielding performance capabilities, a direct radiation shielding test depend on test variables is required. However, doing this in South Korea can be challenge. For this reason, we will compare the shielding performances using the unit volume weight of specimens, indirectly. The relationship between the unit volume weight of heavy weight concrete and the radiation shielding ratio has already been reported by many researchers (Kim et al., 2005; Chang, 1999; Lim et al., 2011). The radiation shielding performance can be estimated by Eqs. (1)–(3) below.

$$S_{28} = 0.0128W + 43.595 \tag{1}$$

$$S_{28} = 0.01038W + 36.5 \tag{2}$$

$$S_{28} = -1E - 05W^2 + 0.086W - 60.824 \tag{3}$$

Here, S_{28} is the radiation shielding ratio at 28 days (%) and W is the concrete unit volume weight (kg/m^3).

Also, the various methods are available to the radiation shield designer for calculating the radiation shielding performance of concrete (Tarim et al., 2013). Some of the techniques, mainly kernel methods, are simple enough (ANSI/ANS-6.4, 2006). Especially, the mass attenuation coefficients are calculated from the existing equation (El-Sayed and Mohamed, 2015). The present literature reviews reported that the mass attenuation coefficient for any mixture can be found from Eq. (4) below.

$$(\mu/\rho)_i \sum_{i=1}^{N} (\mu/\rho)_i f_{wi} \tag{4}$$

where, $(\mu/\rho)_i$ is the mass attenuation coefficient of the ith element, N is total number of elements, and f_{wi} is fractional weight of the ith element.

The gamma rays are attenuated in proportion to the atomic mass of the shielding materials (Osman et al., 2015). The mass attenuation coefficient increases with material density for gamma rays of a given energy group. Since gamma-rays attenuation is dependent upon the shielding materials, the composition and density of the material must be known (Mavi, 2012). This requirement is not always satisfied in concrete shielding designs, owing to the inherent variation in the concrete.

3. Experimental procedure

3.1. Materials

3.1.1. Cement

All of the mortar specimens were produced using Ordinary Portland Cement (OPC) (ASTM Type I). In addition, to investigate the effect of the mineral admixture on the mechanical properties of the mortar, the cement was replaced by a mineral admixture at a water-binder ratio of 35%. The fly ash (i.e., FA) and blast furnace slag (i.e., BFS) replacement ratios were 20% and 50%, respectively. The physical and chemical compositions of the cement and mineral admixtures are shown in Table 1.

3.1.2. Aggregate

River sand having a fineness modulus (F.M.) of 2.79 was used as a natural fine aggregate in the mortar mix. The specific gravity and absorption ratio of this fine aggregate were 2.55 and 1.07%, respectively. Furthermore, crushed heavy weight waste glass was used with a substitution ratio of the fine aggregate by volume. The specific gravity and fineness modulus of the crushed heavy weight waste glass were 3.0 and 3.34, respectively.

The river sand and crushed heavy weight waste glass are shown in Figs. 1 and 2, respectively.

3.2. Variables of test

To investigate the mechanical properties and pore structures with the heavy weight waste glass substitution ratio, an experiment was carried out to evaluate the consistency, compressive strength, flexible strength and pore structures of the mortar. The test variables are listed and summarized in Table 2.

3.3. Mix proportion

The water-to-binder ratios of the specimens were varied at W/B 45% (i.e., 45OPC) and W/B 35% (i.e., 35OPC) for the evaluation of the properties of the mortar. The heavy weight waste glass was used as a substitute for river sand at 0%, 25%, 50%, 75% and 100% by volume.

In addition, to investigate the effects of mineral admixtures on the mortar specimens, part of the cement was replaced by mineral admixtures at a W/B ratio of 35%. The replacement ratio was 20% for FA (i.e., 35FA20) and 50% for BFS (i.e., 35BFS50). The mix proportions for the mortar specimens used in this study are shown in Table 3.