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Efficiency of ground granulated blast-furnace slag replacement in ceramic waste aggregate mortar

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ABSTRACT

From our previous findings, the recycling of ceramic waste aggregate (CWA) in mortar has been proved an ecological means plus an excellent outcome against chloride ingress. The CWAs were porcelain insulator wastes supplied from an electric power company, which were crushed and ground to fine aggregate sizes. In this study, to further develop the CWA mortar as an eco-efficient construction material, ground granulated blast-furnace slag (GGBS) was incorporated. The slag (having the Blaine fineness of 6230 cm^2/g) was utilized as a supplementary cementitious material (SCM) at three different replacement levels of 15%, 30%, and 45% of cement by weight. The efficiency of the GGBS on enhancing chloride resistance in the CWA mortars was experimentally assessed by using a silver nitrate solution spray method and an electron probe microanalysis (EPMA). The tests were carried out on mortar samples after immersed in a 5.0% NaCl solution for 24 weeks. Another set of the mortar samples was exposed to a laboratory ambient condition for 24 weeks and then followed with a carbonation test. The test results indicated that the resistance to the chloride ingress of the CWA mortar becomes more effective in proportion to the replacement level of the GGBS. In contrast, the carbonation depth of the CWA mortar increases with the increase of the GGBS. The activeness of the GGBS was also evaluated on the basis of the compressive strength development up to 91 days. Due to its high fineness, the GGBS can be used up to 30% while the high relative strength (more than 1.0) is achieved at all ages.

1. Introduction

Ceramic wastes discarded worldwide from ceramic industries, demolition/construction sites, and electric power companies are one of the materials possibly recyclable as aggregates and/or pozzolans. The utilization of the ceramic wastes has been investigated by many researchers [1–14]. In the existing literature, there is a shortage of research on the utilization of ceramic waste aggregates provided from electric porcelain insulators. In this study, those are abbreviated to CWAs. Hata et al. [2] found that the compressive strength of concrete was increased when fine aggregates in concrete were partially replaced with ceramic waste powder. Senthamarai et al. [4,12] investigated the mechanical and durability properties on concrete made of crushed porcelain insulator wastes as coarse CWA. They found no difference on the mechanical and permeation properties between conventional concrete and CWA concrete. Jacintho et al. [11] used fine CWA for aggregate in mortar. They mentioned that the compressive strength is increased by a possible pozzolanic reaction. The authors [13,14] also investigated on the compressive strength and the resistance to chloride ingress of mortars containing CWAs made of crushed and ground porcelain insulator wastes which were discarded from an electric power company in Japan. The replacement of entire fine aggregates with the CWA in mortar reduces the chloride ion penetration when compared with the river sand (RS) mortar. The reason for reduction in chloride ion penetration is that the pore structure in the matrix of the CWA mortar is improved.

On the other hand, it is well known that ground granulated blast-furnace slag (GGBS) as a supplementary cementitious material (SCM) with partial cement replacement is effective in the resistance of chloride ingress into mortar and concrete. The physical, mechanical, and durability properties of mortar and concrete with GGBS have been investigated by many researchers so far. The advantages of using GGBS are usually ascribed to long-term strength gain and resistance to weathering and aggressive chemical action [15]. However, it depends on the replacement ratio, particle size, and curing conditions [16]. Sivasundaram and Malhotra [17] investigated the mechanical properties and the durability characteristics of high-volume GGBS concretes. They reported that

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the compressive strength development of concrete incorporating GGBS was lower than that of concrete without GGBS at the early age. However, at the later age, the compressive strength of concrete with GGBS was greater than that of concrete without GGBS. Chikada et al. [18] investigated the resistance of concretes with three different finenesses of GGBS. They reported that the higher fineness of GGBS in concrete showed the higher chloride resistance. Osborne [19] also investigated the performance and durability of concrete with GGBS. He concluded that concrete with high replacement level of 70% GGBS performed well when immersed in sea-water, but carbonated significantly more than Portland cement concretes.

In this study, GGBS was incorporated as a SCM to further develop CWA mortar as an eco-efficient construction material. The cement is partially replaced with GGBS at 15%, 30%, and 45% of cement by weight. The compressive strength development and durability of the CWA mortar with GGBS were investigated. Carbonation and chloride ingress, which are two main issues regarding the durability of cement-based materials were studied. The former was simulated with the exposure to a laboratory ambient condition while the latter was simulated with the immersion in a sodium chloride solution. Both exposures were continued for 24 weeks prior to testing. Colorimetric tests based on the phenolphthalein and the silver nitrate spray methods were conducted to examine the penetration depth of carbonation and chloride, respectively. Chloride transport was further studied by using an electron probe microanalysis (EPMA).

2. Experimental program

2.1. Ceramic waste aggregate

Electric porcelain insulator wastes as shown in Fig. 1 (suspension insulator) were first received from an electric power company in Japan. It was subsequently transformed to fine aggregates namely ceramic waste aggregates (CWAs) at a recycling plant (The Kanden L&A Company, Ltd.) via the processes developed primarily by Sano et al. [20] as follows. Firstly, the ceramic wastes were broken by using a hammer and a jaw crusher to small pieces ranging from 50 to 100 mm size. Next, by using a cone crusher, these pieces were crushed to small grains at a particle size of 30 mm or smaller. These particles have sharp, knife-like edges at this stage, which would be still dangerous to supply as aggregate for mortar and concrete. Therefore, removal of the sharp edges from the CWA was subsequently achieved by a grinding machine. Finally, the particle sizes ranging from 0.075 to 5.0 mm, as displayed in Fig. 2, were used in this study. The CWA has a specific gravity of 2.40 and water absorption of 0.70%. The grain size distribution of the CWA after going through the above process is presented in Fig. 3 with the grading requirements (dashed lines) of the standard distribution specified in JIS A 5005 [21]. The grain size distribution of the CWA is within the standard distribution except for one particle size of 2.5 mm. The fineness modulus of the CWA was 3.20.

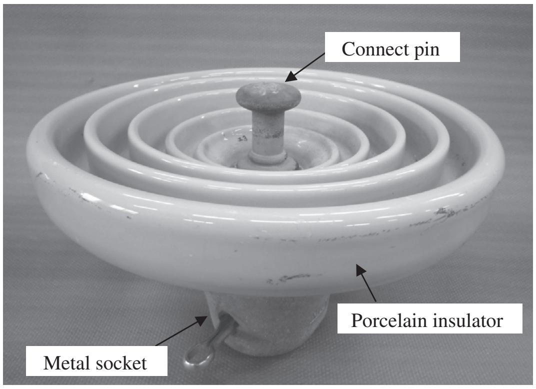

Fig. 1. Suspension insulator.

Fig. 2. Ceramic waste fine aggregates.

2.2. Materials and mixture proportions

To further develop the CWA mortar as an eco-efficient construction material, GGBS supplied from a slag cement company was employed as a SCM in this study. The slag was used as received having a specific gravity of 2.91 and a specific surface area of 6230 cm^2/g. According to the manufacturer specifications, its activity index calculated on the basis of compressive strength was 0.97, 1.11, and 1.27 at 7, 28, and 91 days, respectively. In addition, the cement was ordinary Portland cement (OPC). The physical and chemical properties of all materials used (i.e., OPC, GGBS, and CWA) are given in Table 1.

In the mixture proportion, the water–binder (W/B) ratio was kept constant at 0.5 by weight and CWA–binder (S/B) ratio was also kept constant at 2.0 by weight. The CWA mortar without the GGBS as a control mixture was compared with the modified mixtures in which the cement was partially replaced with GGBS at 15%, 30%, and 45% by weight. They are denoted as CWAM0, CWAM15, CWAM30, and CWAM45, respectively. The CWA was mixed in an air-dry condition due to its low water absorption (0.70%). For all mixtures, the mortars were prepared in a Hobart mixer of 5 L capacity. The mixing process was started with the

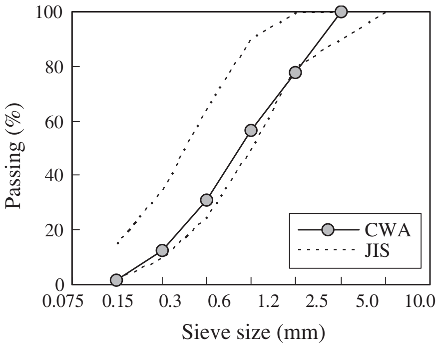

Fig. 3. Grain size distributions.