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Compressive strength and resistance to chloride penetration of mortars using ceramic waste as fine aggregate

Hiroshi Higashiyama [a,*], Fumio Yagishita [a], Masanori Sano [a], Osamu Takahashi [b]

[a] Department of Civil and Environmental Engineering, Kinki University, 3-4-1, Kowakae, Higashiosaka, Osaka 577-8502, Japan
[b] The Kanden L&A Company, Ltd., 1-3-12, Shinmachi, Nishi-ku, Osaka 550-0013, Japan

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ABSTRACT

This paper presents the results of experimental investigation on compressive strength and resistance to chloride ion penetration of mortars made of ceramic waste as fine aggregate. The ceramic waste of electrical insulators provided from an electric power company in Japan has been crushed and ground to produce fine aggregates for mortars in this study. In the process of crushing and grounding, ceramic powder is discharged as a by-product. The effects of mixing with the ceramic powder in mortars have been also investigated. Compression tests of mortars are conducted at 7, 28 and 91 days curing. Moreover, the resistance to chloride ion penetration of mortars has been determined by two methods: the spraying of a 0.1 N silver nitrate solution and the X-ray fluorescence spectrometry. The compressive strength of mortar made of the ceramic waste aggregate increases and the resistance to chloride ion penetration is significantly higher in comparison with mortar made of the river sand. It is also confirmed that a partial replacement of cement by the ceramic powder up to 20% by weight is effective with respect to the compressive strength and the resistance to chloride ion penetration.

1. Introduction

Industrial wastes have continued to increase due to the continued demands of resource use. With increasing restrictions on landfills, industries have to find effective ways for recycling their wastes and by-products. From the viewpoint of the sustainable society, recycle of ceramic wastes from ceramic industries and electric power companies is one of the most important purposes as the global environmental problem. In the year 2009, electric power companies in Japan have discharged ceramic wastes of 3300 t from The Tokyo Electric Co. Inc. [1] and 3100 t from The Kansai Electric Co. Inc. [2].

Some researchers in the world have investigated the effects of using ceramic wastes, such as blocks, bricks, roof tiles, sanitary ware or electrical insulators, as aggregates and/or pozzolanic admixtures in mortar and concrete. There are a number of studies on mechanical properties of mortar or concrete made of ceramic wastes as aggregates [3–13]. The pozzolanic reactivity of ceramic powders from ceramic roof tiles or ceramic electrical insulators has been confirmed [9–11]. Several authors [5–7,12,13] have also investigated on permeability, abrasion resistance, and chloride ion penetration depth of concrete with crushed ceramic wastes. Compressive strength increased and chloride ion penetration depth significantly reduced with the increase in crushed ceramic percentages [6]. However, the effects and mechanical properties on ceramic wastes of electrical insulators provided from electric power industries in mortar and concrete are still limited [4,10,13].

In the present study, the ceramic waste of electrical insulators provided from an electric power company in Japan was used as fine aggregate in mortar. The ceramic powder produced in the process of crushing and grounding of the ceramic waste was also used with a partial replacement of cement or as an admixture. The aim of this investigation is to study the compressive strength and the resistance to chloride ion penetration of mortars containing the ceramic waste aggregate and powder.

2. Experimental programs

2.1. Materials

Ceramic electrical insulators as shown in Fig. 1 were broken by a hammer into smaller pieces with 50–100 mm length. These pieces were crushed using a specially assembled crushing machine into under 30 mm particle size. These ceramic particles had very sharp edges like a knife edge, which were still dangerous to supply as aggregates for mortar and concrete. Therefore, the ceramic particles were ground by an originally developed grinding machine with a 160 L capacity such as Los Angeles abrasion testing machine (Fig. 2). The relation between the particle edge width and grinding time [14] is given in Fig. 3. The safety shape of particle, which has the particle edge width of greater than 0.5 mm, is sufficiently obtained by grinding for 45–60 min. The grain size distribution of ceramic waste fine aggregate

* Corresponding author. Tel.: +81 6 6721 2332; fax: +81 72 995 5192.
E-mail address: h-hirosi@civileng.kindai.ac.jp (H. Higashiyama).

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Fig. 1. Ceramic electrical insulator.

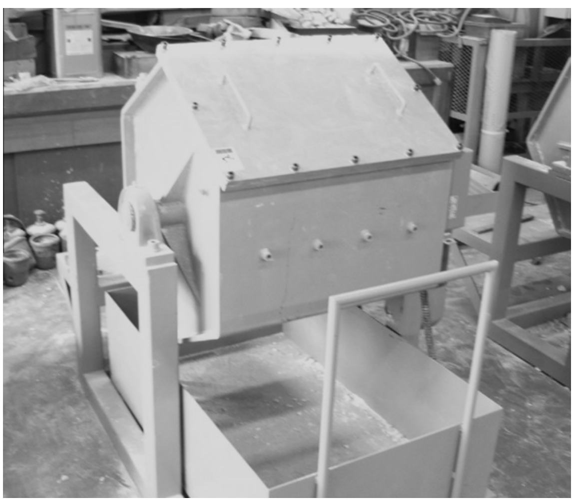

Fig. 2. An originally developed grinding machine.

after grinding for 60 min is shown in Fig. 4 with that of river sand and Japanese Industrial Standards (JIS A 5005). The grain size distribution of ceramic waste aggregate used was adjusted to correspond with that of the river sand for specimens of compression tests in order to provide a direct comparison of their effects on the compressive strength. The ceramic waste aggregate of mortar for the chloride ion penetration test, however, was supplied without making an adjustment of the grain size distribution.

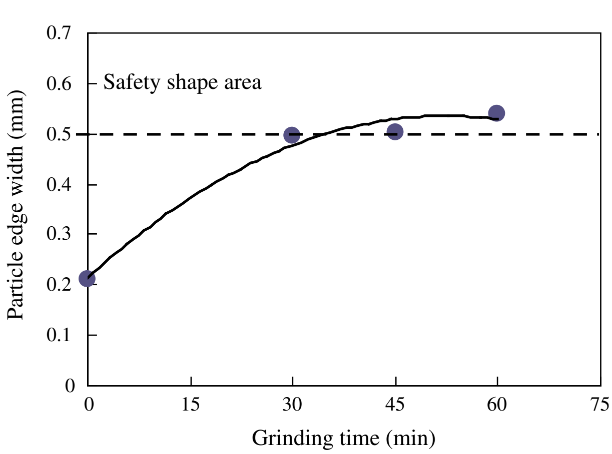

Fig. 3. Particle edge width and grinding time.

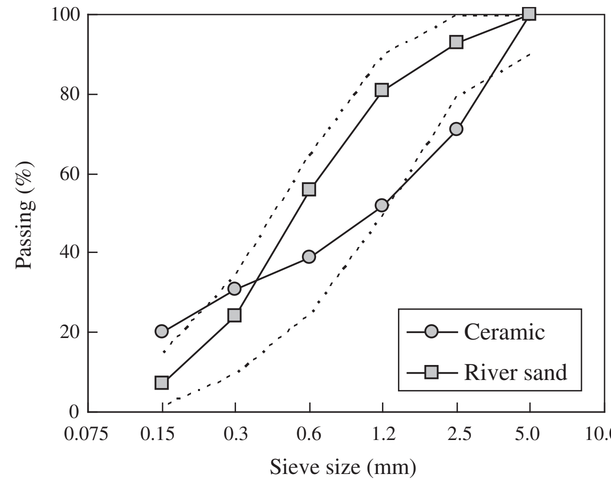

Fig. 4. Grain size distributions of ceramic waste aggregate and river sand.

The chemical composition of ceramic waste from electrical insulators is presented in Table 1. Maximum particle size, specific gravity, water absorption, and fineness modulus of the ceramic waste aggregate and the river sand are presented in Table 2. In this study, the particle size ranging from 5.0 to 0.075 mm was used as fine aggregate and that with smaller than 0.075 mm was employed as a partial replacement of cement or as an admixture. The cement used was an ordinary Portland cement (specific gravity: 3.15, specific surface area: 3360 cm^2/g).

2.2. Mixture proportions

A constant water to cement ratio (W/C) of 0.5 by weight and sand to cement ratio (S/C) of 2.0 by weight were chosen as the basic mixture proportion of mortar. Mixture proportion ratios by weight are summarized in Table 3. A partial replacement of cement by the ceramic powder with the particle size smaller than 0.075 mm was at 10%, 20% or 30% of cement by weight and the addition of ceramic powder to mortars was also at 10%, 20% or 30% of cement by weight. The river sand was mixed in saturated surface-dry condition. On the other hand, the ceramic waste aggregate and powder were mixed in air-dry condition owing to lower water absorption.

2.3. Specimens preparation and test procedures

2.3.1. Compression test

For each mixture, five cylindrical specimens of 50 mm diameter and 100 mm height were cast to determine the compressive strengths after 7, 28 and 91 days curing. The specimens were covered with a plastic waterproof sheet for 24 h after casting and then were demolded and cured in water at 20 ± 2 °C of room temperature until the test age. Compressive load was applied by using a 500 kN capacity universal testing machine and loading speed was a constant of 0.6 $N/mm^2/s$. Only the specimens at 28 days curing were attached two strain gauges on the side surface to determine the elastic modulus.

2.3.2. Pore size distribution test

The pore size distribution test was performed using a mercury intrusion porosimeter. The samples were obtained from each broken cylinder of 50 mm diameter and 100 mm height after 28 days curing. Pore volume of pore size ranging from 0.01 to 10 μm was measured. Specimens, S-1, G-1, GI-2 and GE-2 shown in Table 3, were chosen considering the results of compression test.

2.3.3. Chloride ion penetration test

In this study, the chloride ion penetration test referred to the procedures described in the literature [6,15,16] was conducted. Mortar cylinders of 100 mm diameter and 200 mm height were demolded after 24 h of casting and cured in water at 20 ± 2 °C of room temperature for 7 days. After that, they were cut into 150 mm height with the 50 mm end discarded and were left to dry in laboratory condition for 24 h before application of epoxy coating. The specimens were

Table 1
Chemical composition of ceramic waste from electrical insulators.

Chemical composition (%)							
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2
70.9	21.1	0.81	0.76	0.24	1.47	3.57	0.33