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Quality properties of self-consolidating concrete mixed with waste concrete powder

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HIGHLIGHTS

- The process of manufacturing high quality recycled aggregates increases the generation of WCP.
- The particle surface of WCP is angular with a lot of hydration products attached on it.
- Dumping WCP in a landfill contaminates soil and underground water.
- Improvements can be made for WCP-based SCC by the use of GGBF.

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ABSTRACT

This study has been conducted as part of the research project of utilizing waste concrete powder (WCP) created in large quantity during the production of high quality recycled aggregates as a substitute for ordinary Portland cement. The Blaine fineness and the average particle size of WCP used in the study are 1360 cm^2/g and 90 μm, respectively. AS the main characteristic of WCP, it is particle were angular similar to cement, and hydrated products were attached on the surface of particles. Although the flowability, segregation resistance ability and filling ability of SCC tend to go beyond the target range with an increase of mixing ratio (0, 15, 30 and 45%) of WCP, improvements have been made with a proper use of GGBF. The compressive strength at 28 days has achieved 30 MPa or more at WCP's mixing ratio of 15% and the splitting tensile strength and elastic moduli have shown similar results to those of previous studies. The drying shrinkage rate and carbonation depth of SCC with WCP in it have seen improvements on quality when used together with GGBF rather than WCP alone.

1. Introduction

Our standard of living significantly elevated by the economic development in recent years has resulted in a sharp increase of industrial wastes, which emerges as a major social problem. In particular, construction wastes among industrial wastes are expected to gradually increase due to aging concrete structure, performance degradation and usage, and change of purpose among others, which raises a need to develop technologies designed to efficiently handle construction wastes, including waste concrete and to promote reuse and recycling [1–3].

Concrete wastes account for approximately 65% of construction wastes and nearly all concrete wastes, or 90% of more, are used simply for fill-up or landfill. However, an active research into recycling waste concrete into aggregates for ready-mixed concrete, one of the construction materials is underway, achieving major accomplishments in utilizing effective resources and preserving global environment.

Recently the world is seeing a serious lack of construction aggregates due to restrictions on development of stony mountain and exploitation of river sand and marine sand as part of the plans to prevent damage to the environment damage to the environment. To settle these problems, some researchers are working on using the waste concrete as a concrete aggregate [4–7].

Recycled aggregate produced from waste concrete, different from natural aggregate, has mortar attached on the surface. Therefore, the quality of recycled aggregate largely depends on the amount of mortar on its surface. That is, recycled aggregates are classified into (1) natural aggregates (2) natural aggregate with mortar attached on the surface (3) pure mortar aggregate. These recycled aggregates cannot guarantee required quality as aggregate for concrete due to large range in density and absorption rate. Therefore, concrete made of recycled aggregates is known to have

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much less compressive strength and durability for freezing and thawing compared to concrete made with natural aggregate [8–10].

To produce high quality recycled aggregate, accurate manufacturing technologies are required to run repetitive crushing process. These manufacturing technologies maximize the removal of mortar on surface so that high quality recycled aggregate can be produced. Although these technologies can improve the quality of recycled aggregate, it increases manufacturing costs and produces large amounts of waste concrete powder (WCP).

Currently, waste concrete powder is mostly mixed with clay and is dumped into landfill, raising the issue of securing more space for landfill. In addition, it causes secondary environmental contamination (soil and water pollution), which call for technologies that enable recycling in entire quantity is required in order to reutilize resources and to prevent environmental contamination as well [11,12].

Therefore, this study has looked into possibilities of utilizing WCP as substitute material for cement in producing self-consolidating concrete (SCC) as part of the way to use WCP created in large quantity during the production of high quality recycled aggregates for high-value added construction material.

2. Experimental program

2.1. Materials

The ordinary Portland cement (OPC) with density of 3.15 g/cm^3, waste concrete powder (WCP) with density of 2.49 g/cm^3 and ground granulated blast-furnace slag (GGBF) with density of 2.88 g/cm^3 are used. The chemical components and physical properties are shown in Table 1. Also, fine aggregates used in producing self-consolidating concrete (SCC) whose density and absorption rate are 2.55 g/cm^3 and 2.07%, respectively while crushed aggregates whose density and absorption rate are 2.71 g/cm^3 and 1.01%, respectively have been adopted as maximum size of 20 mm.

To achieve an acceptable flowability for SCC, a polycarbonate-based high-range water reducer or superplasticizer (SP) as per ASTM C 494 type F specification having a density of 1.10 g/cm^3 and a total solid content of 41% was used. The amount of SP and an air-entraining admixture are about 1.0–1.5% and 0.005% of binder weight, respectively.

2.2. Experimental investigations

2.2.1. Quality of waste concrete powder

The size distribution of WCP was analyzed going a particle size analyzer produced by M company, and the grain shape was analyzed using scanning electron microscope (SEM) [13].

Table 1
Chemical components and physical properties of binder.

Types	OPC	WCP	GGBF
SiO_2	21.60	58.55	32.30
Al_2O_3	6.00	10.35	14.80
Fe_2O_3	3.10	4.64	0.40
CaO	61.40	11.82	5.50
MgO	3.40	1.52	1.00
SO_3	2.50	0.44	0.62
Density (g/cm^3)	3.15	2.49	2.88
Blaine Fineness (cm^2/g)	3539	1360	4580

OPC: Ordinary Portland Cement, WCP: Waste Concrete Powder, and GGBF: Ground Granulated Blast-Furnace slag.

2.2.2. Mix design of self-consolidating concrete

Table 2 is the mixture proportions of self-consolidating concrete (SCC) used in this study, and the mixture that has not used WCP and GGBF is the standard SCC mixture (No. 1). The standard SCC mix that has been adopted meets the properties of SCC (slump-flow, time required to reach 500 mm of slump-flow, time required to flow through V-funnel and filling height of U-box test) in the preliminary test.

2.2.3. Fresh concrete test

Table 3 describes the evaluation criteria of SCC that can be used in reinforced concrete structure. Therefore, slump-flow (mm), time required to reach 500 mm of slump-flow (sec.), time required to flow through V-funnel (sec.) and filling height of U-box test (mm) have adopted the values presented in Table 3 as the target values [14].

2.2.4. Hardening concrete test

The specimens used for such tests as compressive strength, splitting tensile strength and the elastic moduli by age have been manufactured without hand compaction or mechanical vibration in a ø100 × 200 mm cylinders, which is removed in 24 h and have been water cured under the temperature condition of 23 ± 2 °C prior to the tests. The compressive strength was measured at 3, 7 and 28 days. The splitting tensile strength and the elastic moduli were measured at 28 days.

Change of length was measured per age by producing the mold of 100 × 100 × 285 mm by ASTM C 157 [15].

Specimen of accelerated carbonation was produced in the same method as mold for concrete compressive strength. After curing for 28 days, the two ends of each specimen were coated with epoxy resin to ensure that carbon dioxide (CO_2) could diffuse only into the specimens in a two-dimensional mode. Insert the specimen in the accelerated carbonation tester produced to keep temperature of 20 ± 2 °C and relative moisture of 60 ± 5% and CO_2 concentration of 10 ± 0.5% and measure the depth of carbonation per input age using phenolphthalein solution [16,17].

3. Results and discussion

3.1. Characteristics of waste concrete powder

Fig. 1 describes the particle size distribution curve of WCP. In Fig. 1, the diameter of WCP particle is measured at 90 μm if the accumulated passing amount of particles is 50%.

Fig. 2 describes the measurement using SEM to look into the particle images of WCP. As shown In Fig. 2, WCP particle has an angular shape, however, it was hydrates such as $Ca(OH)_2$ on its surface. These hydrates contain fine capillary pore. Therefore, compared with OPC, WCP is a more porous material.

3.2. Properties of fresh concrete

Table 4 and Figs. 3–6 show the flowability (slump-flow), segregation resistance ability (time required to reach 500 mm of slump-flow and time required to flow through V-funnel) and filling ability (filling height of U-box) of SCC produced mixed with WCP (0, 15, 30 and 45%) alone and WCP (15, 30 and 45%) with GGBF 15%.

As shown in Fig. 3, the flowability (slump-flow) has decreased by 1.6, 6.4 and 9.6% compare to standard concrete in it as the mixing ratio (15, 30 and 45%) of WCP increases. In particular, WCP with its mixing ratio between 30 and 45% does not meet the target range, which is apparently attributed to a lot of hydration products attached to the particle surface of WCP absorbing mixing water and consequently degrading flowability. However, the flowability