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Effects of waste PET bottles aggregate on the properties of concrete

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Abstract

This paper investigates the surface microstructure of waste polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) to examine the effect of granulated blast-furnace slag (GBFS) on WPLA. The WPLA was made from the waste PET bottles and GBFS, and experimental tests were conducted on compressive strength, splitting tensile strength, modulus of elasticity, slump, and density of waste PET bottles lightweight aggregate concrete (WPLAC).

The 28-day compressive strength of WPLAC with the replacement ratio of 75% reduces about 33% compared to the control concrete in the water–cement ratio of 45%. The density of WPLAC varies from 1940 to 2260 kg/m^3 by the influence of WPLA. The structural efficiency of WPLAC decreases as the replacement ratio increases. The workability of concrete with 75% WPLA improves about 123% compared to that of the normal concrete in the water–cement ratio of 53%. The adhered GBFS is able to strengthen the surface of WPLA and to narrow the transition zone owing to the reaction with calcium hydroxide.

Keywords: Waste PET bottles lightweight aggregate; Microstructure; Granulated blast-furnace slag; Compressive strength; Workability

1. Introduction

Lightweight aggregate is an important material in reducing the unit weight of concrete complying with special concrete structures of large high-rise buildings. Generally, lightweight aggregate is made from ground granulated blast-furnace slag (GBFS), fly ash, and volcanic ash [1,2]. However, lightweight aggregate is faced with some problems: (1) the high cost of aggregate due to high incineration temperature; (2) the shrinkage and resistance to freezing and thawing because of high absorption of lightweight aggregate [3,4]. Therefore, the improvement on the quality of lightweight aggregate concrete has attracted much attention from researchers [5–7].

On the other hand, polyethylene terephthalate (PET) bottles have taken the place of glass bottles as storing vessel of beverage due to its lightweight and ease of handling and storing. As the beverage consumption increases drastically, the production of PET bottles increased exponentially as it was reported that PET bottles were produced about 87,000 tons at the end of 2002 in Korea [8].

Because the Korean Government established laws on conservation and recycling of resources to prevent environmental contamination and resource dissipation, the recycling of waste PET bottles has been designated as a priority management item [9].

Waste PET bottles had been reworked for drinking bottles by melting fusion, which turned out to be too costly. Then, waste PET bottles were insured to recycling as lightweight aggregates to reduce the rework cost. However, results have been far from satisfactory. If waste PET bottles were reused as lightweight aggregates for concrete, positive effects are expected on the recycling of waste resources and the protection of environmental containment.

Furthermore, GBFS is sufficiently able to react with calcium hydroxide to form calcium silicate hydrate (C-S-H) as a pozzolanic material. Then, the transition interfacial zone between aggregates and cement paste will be strengthened because the GBFS consumes the calcium hydroxide. The GBFS is able to improve the workability as well as the resistance to chemical attack and reduce the heat of hydration because the pozzolanic reaction is quite slow [10,11].

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Table 1
Chemical compositions of cementitious materials

Components	C (%)	GBFS (%)
SiO_2	21.60	33.33
Al_2O_3	6.00	15.34
Fe_2O_3	3.10	0.44
CaO	61.41	42.12
MgO	3.40	5.70
SO_3	2.50	2.08

Table 2
Physical properties of aggregate

Components	RS	WPLA	Coarse aggregate
Density (g/cm^3)	2.60	1.39	2.69
Bulk density (kg/m^3)	1677	844	1589
Absorption (%)	1.82	0.00	0.86
Percentage of solids (%)	64.5	60.7	58.0
Fineness modulus	2.90	4.11	7.15

In this study, lightweight aggregates were made from waste PET bottles, and GBFS was used to examine whether it is possible to improve the quality of lightweight aggregate. We investigated the quality of lightweight aggregates, conducting tests on the workability and the strength properties of concrete, analyzing the relationship between the quality of aggregates and the properties of concrete.

2. Experimental outline

2.1. Materials

Korean normal portland cement (C) and the GBFS were used as cementitious materials. The density and Blaine fineness of normal portland cement are 3.15 g/cm^3 and 3539 cm^2/g, respectively, and the density and Blaine fineness of GBFS are 2.90 g/cm^3 and 3840 cm^2/g, respectively. The characteristics of the normal portland cement and the GBFS are shown in Table 1.

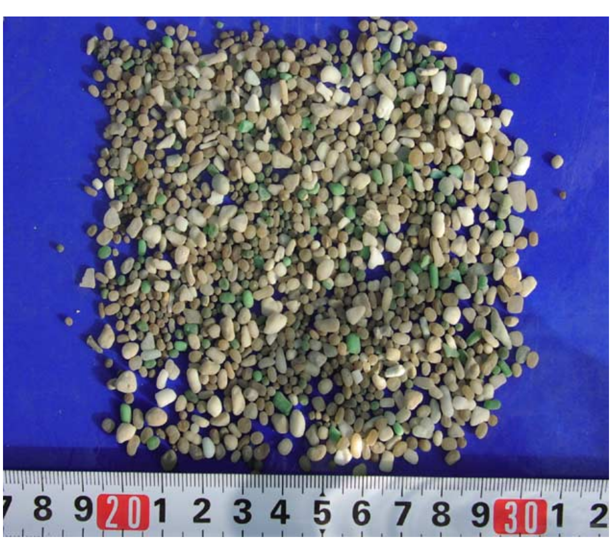

Fig. 1. Shape of WPLA.

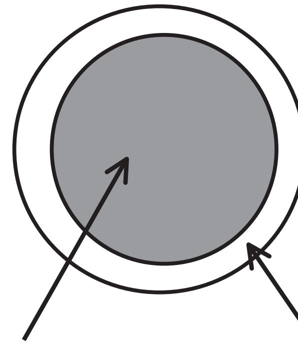

Fig. 2. Section of WPLA.

The fine aggregates are clean river sands (RS) and lightweight aggregates made from waste PET bottles (WPLA). The coarse aggregate is crushed stone aggregate with a maximum size of 20 mm. Both the fine and coarse aggregates are sufficient in satisfying the Korean Standard Specifications. The physical properties of the aggregates are shown in Table 2. Standard type of AE Water-Reducing Agent (AE) was used in this experiment, and the specific gravity and pH of AE are 1.2 ± 0.02 and 7.0 ± 1.0, respectively.

Lightweight aggregates were manufactured from the waste PET bottles according to the following procedure. The fractions of waste PET bottles cut to the range of 5–15 mm were intruded in the mixer. The inner temperature and rotate velocity of the mixer were 250 ± 10 °C and 30–50 rpm for 20 s. The GBFS was entered in the mixer with the waste PET bottles to solidify the surface of aggregates.

The density and bulk density of the WPLA are 1.39 g/cm^3 and 844 kg/m^3, respectively, and its absorption was not measured in Table 2. Fig. 1 indicates the smooth sphere shape of the WPLA. Fig. 2 shows the section of WPLA, and GBFS is uniformly covered on the surface of aggregates.

Table 3
Mixture proportions of concrete

Mix number	WPLA: (RS + WPLA)	S/a [%]	W/C	C:AE
1, 2, 3, 4	0:1, 0.25:1, 0.5:1, 0.75:1	48.4, 50.9, 53.4, 56.4	0.53	1:0.003
5, 6, 7, 8	0:1, 0.25:1, 0.5:1, 0.75:1	47.0, 49.5, 52.0, 55.0	0.49	1:0.003
9, 10, 11, 12	0:1, 0.25:1, 0.5:1, 0.75:1	45.9, 47.9, 50.9, 53.9	0.45	1:0.003