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An approach for the recycling of waste concrete powder as cementitious materials

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Recycled concrete powder, which was generated by crushing waste concrete, was reutilized as concrete material. The experiment intends to perform several tests for the exploitation of recycled concrete powder as cementitious material. The recycled concrete powder significantly influences the properties of mortar according to the type of recycled concrete powder, replacement ratio, and mix design. The flexural strength and compressive strength after 28 days of the mortar mixed with matrix recycled concrete powder was slightly larger than that of mortar using demolished recycled concrete powder. Thus, the use of recycled concrete powder will be promoted and realized through the utilization of self-consolidating concrete, pavement concrete, and roller compacting concrete.

Key words: Recycled concrete powder, Waste concrete, Replacement ratio, Compressive strength.

Introduction

Construction wastes are increasing rapidly with the growth of the construction industry. Approximately 70% of these wastes are constituted of concrete wastes [1-4]. Thus, there is an urgent need to establish a recycling technology that reutilizes concrete wastes as the material for fabrication of concrete in regard to environmental protection and optimized exploitation of resources. Toward this goal, diverse policies and exploitation programs have been proposed by academia and industry [5-7].

The crushing of concrete wastes produces coarse aggregates, fine aggregates, and powder. Researches to recycle the coarse and fine aggregates so-produced for the construction of road base and sub-base courses as well as aggregates for mixing of concrete are actively conducted all over the world [8-9]. On the other hand, the volume of recycled concrete powder is increasing significantly during the production of high added-value and high quality coarse aggregates to reach about 10 to 20% of the matrix concrete, which has led researchers to undertake studies to reutilize the so-generated powder [10].

Recycled concrete powder (RCP) is produced by the separation of matrix concrete and cement paste (Fig. 1). Even if its characteristics depends on the age and strength of the matrix concrete as well as environmental conditions, recycled concrete powder also presents cementitious content. Therefore, this study intends to perform several tests for the exploitation of recycled concrete powder as concrete material. In order to reach this goal, a total of 6 types of recycled concrete powder have been prepared by dismantlement and crushing of actual concrete structures and matrix concrete. The compressive strength, flexural strength, and fluidity of mortar using recycled concrete powder were observed.

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Experimental

Ordinary Portland cement was used in this study. Recycled concrete powder was obtained by crushing concrete masses, from which fine aggregates smaller than 0.2 mm were oven-dried for 24 hours at 105 ± 5 °C. The 3 types of recycled matrix concrete powder (low recycled concrete powder, medium recycled concrete powder, high recycled concrete powder) were prepared by crushing low strength (28.3 MPa), medium strength (49.0 MPa) and high strength (60.7 MPa) concrete-matrix. The 3 types of demolished recycled concrete

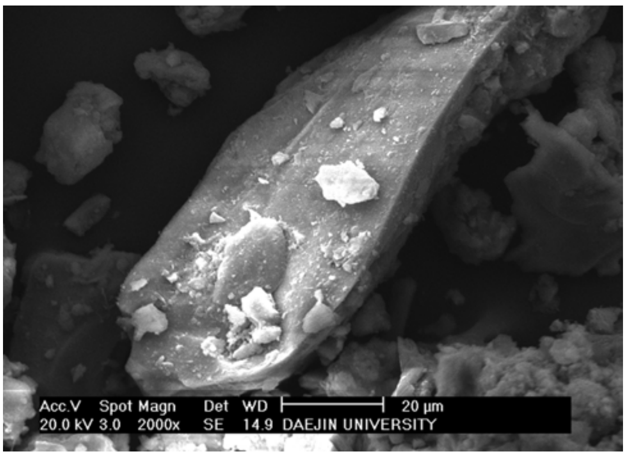

Fig. 1. SEM image of recycled concrete powder.

powder (DRCP1, DRCP2, DRCP3) were prepared by crushing the concrete obtained from demolished concrete structures. The recycled concrete powder included more than 40% of insoluble components, and the ignition loss exceeded 16%. Standard sand was used as a fine aggregate, and the admixture was a superplasticizer composed mainly of highly-concentrated naphthalene sulfate.

The mix proportion of mortar was with a water-cement ratio of 0.5, and a fine aggregate-cement specific weight of 3.0. Recycled concrete powder was used to replace the cement at ratios of 10%, 20% and 30% of the cement specific weight.

In order to examine the basic properties of RCP, the chemical composition of RCP was analyzed using XRF (Philips, PW1400). The internal porosity of RCP was measured by means of a mercury intrusion porosimeter.

The flow of the mortar was measured in compliance with the regulations of JIS R 5201 so as to survey the properties of mortar mixed with recycled concrete powder. In addition, the compressive and flexural strengths of mortar specimens 4 × 4 × 16 cm, which were fabricated by following the method prescribed by JIS R 5201, were determined. The strengths were measured using a UTM (Shimadzu, UH-I) at 7 and 28 days for the specimens that have been water-cured for a definite period.

Results and discussion

X-ray diffraction was performed in order to verify the activation of the material. Figure 2 shows the X-ray diffraction pattern for recycled concrete powder. X-ray diffraction can be used to determine the amount of crystalline and amorphous material. The amorphous portion of the material is represented by the area under the diffraction curve. The result showed that the recycled concrete powder contains an amorphous phase and that this might allow for reactive material.

Table 1 shows the test results of mortar in terms of the replacement amount of mortar by RCP. The flow decreases in proportion to an increase in the replacement ratio with RCP. The decreasing rate of flow in proportion to the increase in the replacement ratio ranges between 1.46 and 1.50 on average. This observation is in good agreement with the results of Sakai et al. [11] and can be explained by the adsorption of the mixing water to the mortar due to the porosity of RCP.

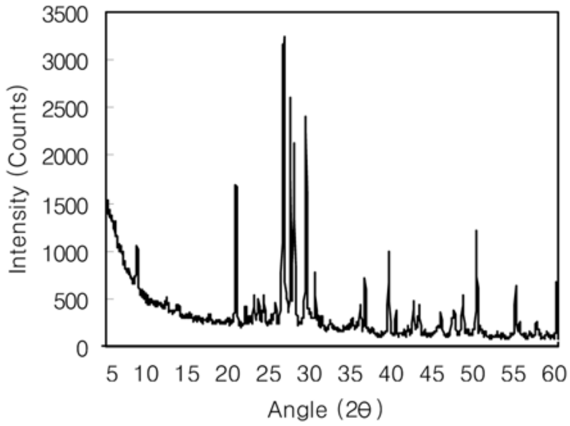

Fig. 2. X-ray diffraction pattern for recycled concrete powder.

The compressive and flexural strengths were measured with time elapsed to evaluate the effects of RCP on the strength characteristics of mortar mixed with RCP. The corresponding results are also summarized in Table 1. The compressive strength at 28 days of mortar using ordinary cement reached about 54 MPa, which was an increase of the strength by approximately 26% compared to the compressive strength of 43.0 MPa measured at 7 days. Similar amounts of increasing strength by age were observed by varying replacement ratios with RCP. For a replacement ratio of 20% of RCP, the compressive strength at 28 days for LRCP, MRCP and HRCP increased by about 39%, 55% and 43% compared to the one at 7 days, and the increasing amount by age was larger than that of mortar using ordinary cement only. In addition, the increasing amount of flexural strength at 28 days with respect to that at 7 days did not show a particular difference by varying the replacement amount with RCP and strength of the matrix concrete. The increasing amount of the flexural strength also appeared to be greater by 2 to 2.7 times than the amount of 12% observed for mortar using ordinary cement only. The reason for the large increasing amount of strength

Table 1. Test results of mortar mixed with concrete-matrix RCP

Types	RCP (%)	Flow value (cm)	Air Content (%)	Compressive strength of matrix concrete (MPa)		Flexural strength of mortar (MPa)		Compressive strength of mortar (MPa)	
				7days	28days	7days	28days	7days	28days
OPC	0	179.0	8.6	42.3	48.5	7.9	8.9	43.0	54.1
LRCP	20	142.3	8.6	18.1	24.4	6.3	8.0	30.2	41.9
MRCP	10	152.9	8.2	33.8	40.5	7.4	9.2	35.7	52.6
MRCP	20	136.0	7.8	33.8	40.5	6.4	8.5	30.2	46.7
MRCP	30	126.6	7.6	33.8	40.5	5.6	7.5	26.7	36.4
HRCP	10	158.5	7.8	47.1	56.1	7.1	8.5	35.9	50.1
HRCP	20	133.6	7.4	47.1	56.1	6.3	7.9	30.3	43.4
HRCP	30	125.5	7.8	47.1	56.1	5.4	7.3	26.4	37.3

by aging the mortar using RCP can be found in the persistence of C_2S, which is a hydrated composition influencing the long-term development of the strength, inside RCP for a certain period.

The effect of the strength of the matrix concrete on the strength characteristics of mortar mixed with RCP is also given in Table 1. It appears that the compressive strength of mortar mixed with RCP exhibits similar values regardless of the strength of the matrix concrete. For equivalent replacement ratios, the strength of the mortar was not sensitive to the quality of the RCP, which meant that the development of strength depended essentially on the hydration of the cement.

Figure 3 exhibits the compressive strength at 28 days of mortar mixed with DRCP as a binder. It can be seen that the compressive strength of mortar mixed with DRCP decreases with increasing amount of replacement with RCP. That difference is due to the difference in the development of strength by the type of RCP. The compressive strength of mortar mixed with 10% of DRCP3 reached about 47 MPa, which corresponded to approximately 87% of the strength developed by the mortar, which was not mixed with any RCP. The influence of RCP on the development of strength of the mortar mixed with RCP observed depends on various factors such as the original strength of the concrete structure, the conditions of the concrete structure due to the external environment, the treatment and management processes of the powder obtained by crushing the concrete structure, which makes it difficult to evaluate the phenomenon clearly.

Figure 4 shows the size distribution of internal pores of DRCP in order to examine the effects of DRCP on the compressive strength of the mortar. DRCP1 exhibits essentially a distribution of capillary pores of 10 mm-30 mm and DRCP3 presents a uniform scattering of pore size from 0.3 mm-20 mm. Also, DRCP2 shows a wide distribution of capillary pores ranging from 0.1 mm to 100 mm. DRCP2 is thus the material in which internal pores are able to adsorb the most of the mixing water and decrease the strength of the mortar.

Figure 5 compares the strengths developed by the mortar using DRCP and the mortar using matrix RCP. The development of the flexural strength and compressive strength at 7 days of the mortars is similar for both mortars using DRCP and matrix RCP. However, the compressive strength developed at 28 days by the mortar using DRCP appears to be smaller than that of the mortar using matrix RCP. This can be explained by the quasi-absence of an activation reaction of the DRCP to enhance the development of the mortar strength, while C_2S in mortar using matrix RCP helps the develop-ment of long-term strength for a definite period.

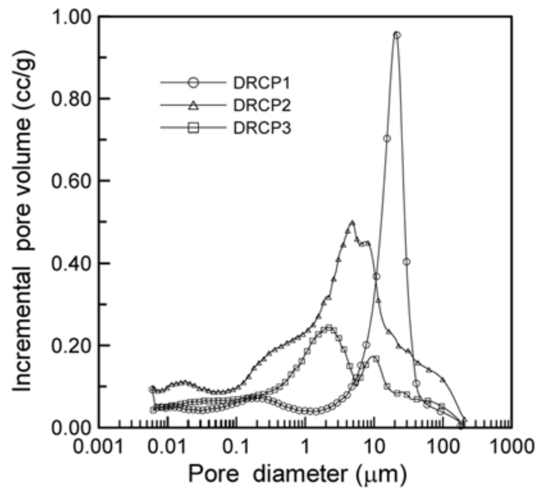

Fig. 4. Distribution of internal pores of DRCP.

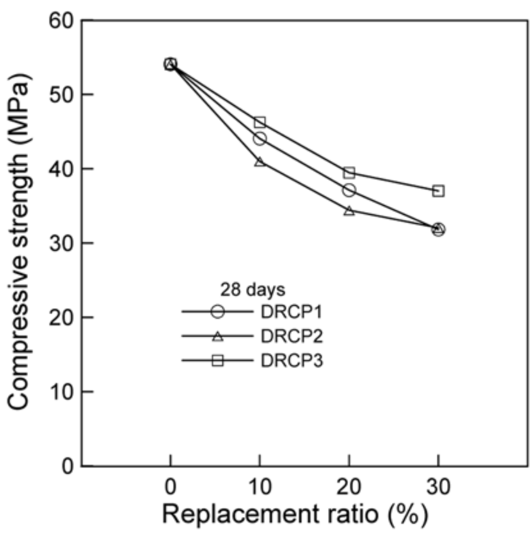

Fig. 3. Compressive strength of mortar using DRCP as a binder.

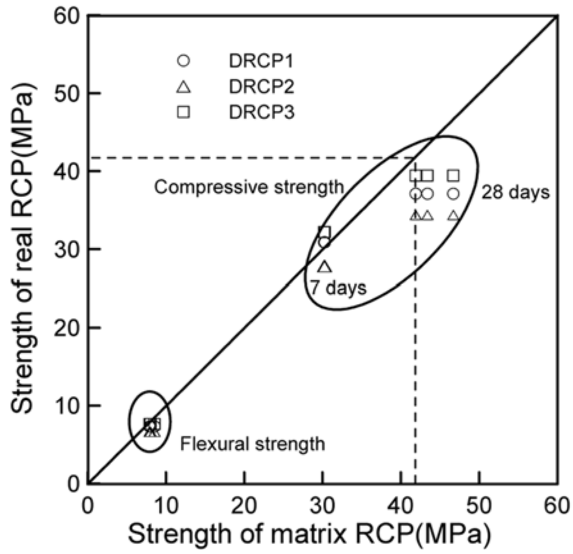

Fig. 5. Comparison of strengths of mortars using matrix RCP and DRCP.

As has been shown, the replacement of cement by matrix RCP degrades the fluidity because of absorptiveness, which requires constructability. Moreover, even if a slight increase in strength occurs with time, the development of strength in accordance with increased replacement ratios was not observed. Thus, the promotion of the exploitation of RCP will be realized through an increase in the activation reaction of RCP and/or the utilization of high-fluidity or self-compacting concrete.

Conclusions

The developed strength and flow of mortar using RCP as a binder decreased proportionally to the increase in the replacement ratio of RCP. The flexural strength and compressive strength at 7 days of the mortar mixed with matrix RCP were similar to the mortar using DRCP. The compressive strength at 28 days of the mortar mixed with matrix RCP was slightly larger than that of mortar using DRCP. Thus, the use of recycled concrete powder will be promoted and realized through the utilization of self-consolidating concrete, pavement concrete, and roller compacting concrete.

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