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Effects of carbonated hardened cement paste powder on hydration and microstructure of Portland cement

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HIGHLIGHTS

- Use CO_2 to treat harden cement powder as a supplemental cementitious material.
- The incorporation of carbonated cement powder enhances the compressive strength.
- Replacement of cement with carbonated cement powder shows a denser microstructure.

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ABSTRACT

Recovering aggregates from recycled concrete produces a large amount of powder, which contains hardened cement paste and is classified as a corrosive hazardous material. This study used CO_2 to treat hardened cement paste powder and to investigate how the incorporation of uncarbonated and carbonated hardened cement paste powder into cement affects the hydration and microstructure development of cement. Carbonated hardened cement paste powder consists mainly of calcite and silica gel. Replacement of cement by uncarbonated cement paste powder content from 10 to 30% by the mass of cement decreases, while replacement of cement with 10–20% carbonated hardened cement paste powder increases the strength of cement up to 90 days. The replacement of cement with 30% carbonated waste paste powder slightly decrease the strength of the cement. The silica gel in carbonated hardened cement paste powder quickly reacts with calcium hydroxide and results in the formation of more C-S-H. The presence of calcite in carbonated hardened paste powder leads to the formation of calcium aluminate hemi-carbonate (CAHC) and calcium aluminate mono-carbonate (CAMC) thus to a stabilization of ettringite (AFt) compared with the control cement paste, in which portion of AFt converts to monosulphoaluminate. CAHC is less stable than CAMC and transforms to CAMC in about one week after its formation. These chemical actions lead to a lower porosity and a higher compressive strength for cement paste with carbonated hardened paste powder compared with the control cement paste.

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1. Introduction

As one of the widely used man-made building materials, the consumption of concrete has been greatly increased, especially with the rapid development of economy and urbanization. The development of the construction industry and depletion of natural resources have caused inevitable contradiction. On one hand, huge amounts of carbon dioxide (CO_2) are released during cement production, which contributes to the global warming and climate change [1]. On the other hand, enormous construction and demolition wastes are generated [2]. Thus, effective utilization of recycled concrete from construction and demolition wastes not only saves the consumption of natural resources, but also alleviates the problem of land occupancy and environmental pollution. The common practice for the utilization of recycled concrete is to produce aggregate. However, some properties, such as compressive and tensile strength, permeability, durability of the recycled aggregate concrete (RAC) made with 100% recycled concrete aggregate (RCA), were 60% lower than those of concrete with natural aggregate [3,4] due to the adhered mortar on recycled concrete aggregate. Shi et al. [5] reported that the mortar made with carbonated RCA showed significantly increased strength, and reduced drying shrinkage, water absorption, and chloride migration

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coefficient. CO_2 can enter into the pores of adhered old mortar and react with calcium hydroxide (CH) and C-S-H so to reduce the porosity, water absorption and crushing value of RCA.

The production of RCA during the crushing of recycled concrete produces more than 10%-20% waste powder at the same time. The waste powder contains a very high portion of hardened cement paste. It is difficult to utilize the powder due to its low activity and higher water requirement. Some studies used the waste powder as an inert filler in replacement of stone powder for the manufacture of concrete products and raw materials of cement [6,7]. Kwon et al. [8] reported that the smaller particle size of waste powder presents higher surface area and activity, which can be used as a supplementary cementitious material.

This paper investigates how incorporation of uncarbonated and carbonated hardened cement paste powder into cement affects the hydration and microstructure development of cement. The progressive hydration and microstructure changes were characterized by heat of hydration, thermogravimetric analysis (TGA), X-ray diffraction (XRD), Fourier Transform infrared spectroscopy (FTIR) and mercury intrusion porosimetry (MIP). The results from this study will provide the scientific knowledge for the carbonation and use of waste cement paste powder during the crushing of RCA.

2. Materials and methods

2.1. Materials

P.I 42.5 Portland cement (PC) with a specific surface area of 336 m^2/kg was used in this study and its chemical composition is shown in Table 1.

2.2. Preparation and carbonation treatment of hardened cement paste powder

Firstly, cement pastes were prepared with a water to cement ratio of 0.4 and cast into 150 mm cubic steel moulds. The specimens were demolded 24 h after casting then cured in lime saturated water tank at 20 ± 1 °C for 90 days. After curing, all specimens were crushed then ground in a ball mill for 30 min. The ground cement paste powder was sieved to pass 75 μm, then placed in a CO_2 chamber at 20 ± 1 °C and relative humidity (RH) of 60 ± 5% for carbonation until the powder was completely carbonated. CO_2 gas with a concentration of 99% was used. The particle size distributions of PC, uncarbonated cement paste powder (UCPP) and carbonated cement paste powder (CCPP) are shown in Fig. 1. It can be seen from Fig. 1 that the three powders have very similar particle size distribution.

2.3. Separation of silica gel from CCPP

Carbonated fully hydrated cement paste consists mainly of calcium carbonate and silica gel. Silica gel is usually stable in acidic environment and only reacts with hydrofluoric acid, while calcium carbonate decomposes very quickly in acidic environment. CCPP was stirred in HCl solution with a concentration of 0.2 mol/L at solid-to-solution ratio of 0.2 for 12 h at the temperature of 22 ± 1 °C then filtered to separate silica gel. The residue on filter paper was stirred in the HCl solution and filtrated for 3 times, then the residue was washed with deionized water to remove the chloride ion. The final residue was filtered and dried in an oven at 60 °C for 48 h. The separated silica gel was kept in a sealed bottle for further analyses.

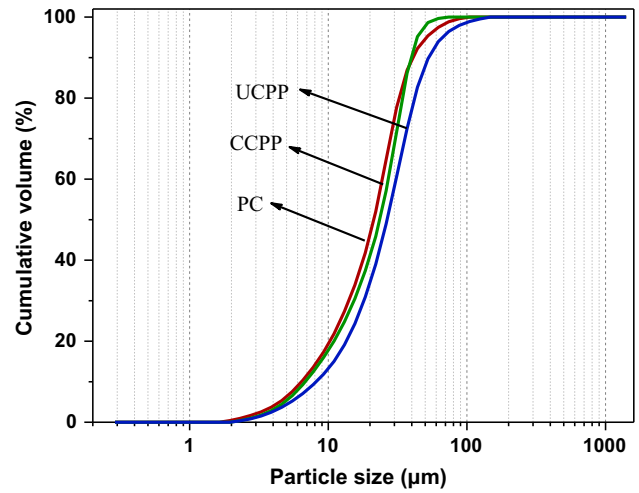

Fig. 1. Particle size distribution of PC, UCPP and CCPP.

2.4. Preparation of cement pastes with CCPP and UCPP

Cement pastes containing CCPP and UCPP were prepared with a water-to-binder ratio of 0.4. The mixture proportions of the cement pastes are given in Table 2. The cement pastes were mixed in a mixer for 3 min and vibrated for consolidation. The cement pastes were cast into 40 mm plastic cubic moulds for compressive strength testing and microstructural analyses. All the specimens were demolded 24 h after casting then cured in a curing room at 20 ± 2 °C and RH of 95 ± 5% until the testing ages.

2.5. Testing methods

2.5.1. Compressive strength

The compressive strength of the cement paste was measured at the age of 1, 7, 28 and 90 days using a compression machine with a loading capacity of 120-KN. The loading rate was 0.6 MPa/min until the specimens failed. The average compressive strength values of three samples were reported.

2.5.2. X-ray diffraction analysis

CCPP, UCPP, and cement pastes with CCPP and UCPP at different ages were dried in an oven at 60 °C for 48 h before analyses. The step-scanned XRD pattern measurements of each sample powder

Table 2
Mixture proportions of cement paste (*w*/%).

	Cement (kg/m^3)	CCPP (kg/m^3)	UCPP (kg/m^3)	Water (kg/m^3)
PC	400	0	0	160
C10	360	40	0	160
C20	320	80	0	160
C30	280	120	0	160
UC10	360	0	40	160
UC20	320	0	80	160
UC30	280	0	120	160

Table 1
Chemical composition of cement (*w*/%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	LOI
21.91	5.30	3.67	64.5	1.51	0.62	0.19	2.03	2.49

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