Influence of Calcium Carbonate from Powder Wastes from Concrete Recycling on the Hydration and Performance of OPC and Slag Blended Cement

Shibaura Institute of Technology Graduate School of Engineering and Science Regional Environment Systems ○Karen Midori Masunaga
Shibaura Institute of Technology Department of Civil Engineering Takeshi Iyoda

1. Introduction

To achieve further CO_2 emission reduction and enhance the circularity in the cement and concrete industry, carbon capture and utilization combined with recycling of concrete has been evaluated recently. In this study, the influence of calcium carbonate from accelerated carbonation of powder wastes from concrete recycling on the hydration mechanism and mechanical performance of Ordinary Portland Cement (OPC) and ground granulated blast furnace slag (GGBS) blended cement was investigated, in order to evaluate the possibility to reintroduce these by-products into the lifecycle of concrete.

2. Materials and Methods

2. 1 Pastes and mortar mixes

OPC (N mixes) and OPC with 50% GGBS replacement (B mixes) were used as binders. Two types of powder wastes were collected from a concrete recycling plant located in Tokyo: recycled concrete aggregate powder (RCAP), obtained from the crushing and sieving process of demolished concrete to produce recycled aggregate; and returned fresh concrete sludge waste (CSW), obtained by dewatering the sludge from returned fresh concrete, after removing the aggregates by a washing process. RCAP and CSW powders were carbonated in an accelerated carbonation chamber 5% CO_2 concentration, 60% relative humidity, 20ºC temperature for 7 days. To ensure a high degree of carbonation of powder cementitious materials, water was added and mixed during the carbonation period to keep the water/solid ratio higher than 0.50 and the powders were dried before mixing. Pure natural $CaCO_3$ from limestone powder (LSP) was also used in the mixes.

Mortar specimens were prepared with water-to-binder ratio (W/B) of 0.55, sand-to-cement ratio of 3 and the powders were added replacing 15% of the sand in mass. Pastes were mixed with W/B of 0.40 and powders were added replacing 15% of the binder in mass. This mix proportions were set to ensure workability and keep the water-to-total powder (binder + powder) ratio of mortar and pastes similar. The identification of powders and mixes is presented in the Table 1.

2. 2 Experimental Tests

Mortar and pastes cylindrical φ50x100 mm specimens were cast and cured in water for compressive strength test and the Archimedes porosity test method was conducted. The heat of hydration of pastes was analyzed by calorimetry equipment and mineral phases composition was determined combining X-ray diffraction (XRD) and thermogravimetric analyses (TGA). XRD patterns were obtained for ground samples, using a Bruker AXS D2 Phaser. TGA was carried out on a Netzsch equipment and the samples were heated from 25°C to 1000°C, at a heating rate of 20°C/min, in N_2 atmosphere.

3. Results and Discussion

3. 1 Influence of combining $CaCO_3$ with GGBS

The compressive strength of mortars is shown in the Fig. 1(a). With the addition of the powders, GGBS blended mortar samples showed better mechanical performance than OPC. For pastes oppositely, powders' addition resulted in better performance combined with OPC, as shown in Fig. 1(b). As the main difference concerning mortar and pastes is the existence of interfacial transition zone (ITZ) between cement matrix and fine aggregates, the porosity volume composed by the ITZ was calculated from pastes and mortar's porosities, using a simplified method, in which the porosity of sand was considered null and the densities of the powders were considered equivalent. The Fig.

Table 1 Pastes and mortar mixes and powders identification

Mixes			Powders			
Identification		Binder	Identification		$CaCO_3$ content	D50 (μm)
1	N	N	--		--	--
2	B	B				
3	N-LSP	N	LSP	Limestone Powder	99%	6
4	B-LSP	B				
5	N-RCAP	N	RCAP	Recycled concrete aggregate powder	36%	46
6	B-RCAP	B				
7	N-CRCAP	N	CRCAP	Carbonated RCAP	35%	40
8	B-CRCAP	B				
9	N-CSW	N	CSW	Concrete sludge waste	7%	33
10	B-CSW	B				
11	N-CCSW	N	CCSW	Carbonated CSW	44%	15
12	B-CCSW	B				

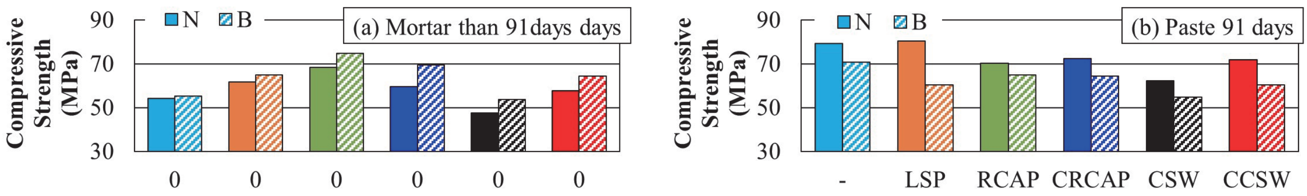

Fig. 1 Compressive strength of OPC and GGBS blended cement (a) mortars and (b) pastes.

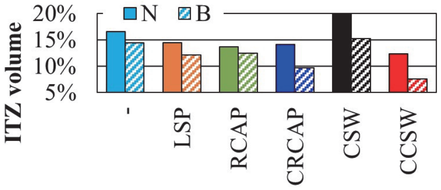

Fig. 2 Calculated ITZ of mortars.

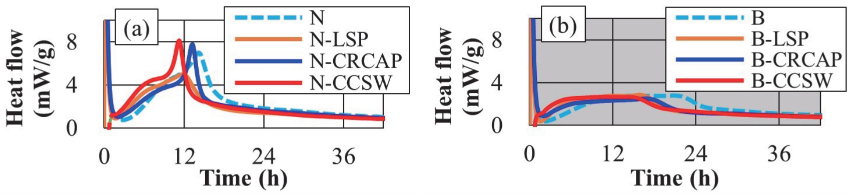

Fig. 3 Heat flow profiles for (a) OPC and (b) GGBS blended cement pastes.

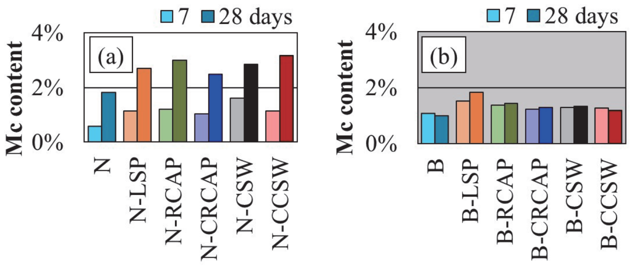

Fig. 4 Monocarbonate content in (a) OPC and (b) GGBS blended cement pastes from XRD.

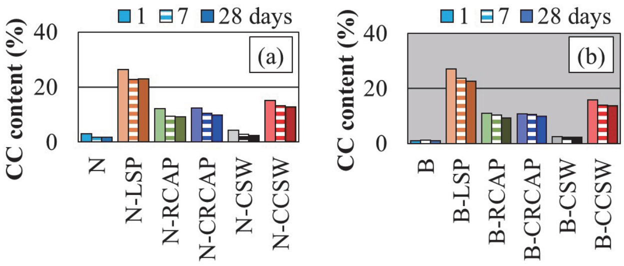

Fig. 5 $CaCO_3$ content in (a) OPC and (b) GGBS blended cement pastes from TGA.

2 shows the estimated values. It indicates that, except for CSW, which was a low $CaCO_3$ content powder and showed increased ITZ for both N and B mixes, $CaCO_3$ combined to GGBS acted reducing the ITZ of mortars and, consequently, increasing the compressive strength. In other words, as GGBS addition to the system creates a more refined microstructure, the presence of some unfilled space in ITZ, existent only in mortar samples, was necessary to effectively explore the potential ability of $CaCO_3$ to serve as more than just a filling material, which was diminished in the case of cement pastes.

3．2 Effect of $CaCO_3$ from different sources

From Fig. 1(a), carbonation of CSW, transforming it into CCSW and increasing $CaCO_3$ content, resulted in improving mechanical performance. However, even though LSP was a fine-grained and pure $CaCO_3$ powder, the RCAP addition showed the highest mortar compressive strength, suggesting that the excess of $CaCO_3$ from LSP may have led to clogging at early ages and hydration inhibition in mortar. These results also indicate that there are ideal $CaCO_3$ content and conditions to explore this mineral admixture reactivity. In the case of powder wastes, it varies depending on the carbonation treatment and the amount of aggregate particles coming from the recycling process.

The chemical effect of $CaCO_3$ can be observed by the left shift on heat evolution profiles with powders addition (Fig. 3), reducing the time to the heat peak. The hydration rates acceleration and the change in mineral phases composition at early ages, noted in the increase of monocarbonate (Mc) content (Fig. 4), combined with the decrease of $CaCO_3$ content (Fig. 5) are indications that $CaCO_3$ from concrete powder wastes shows similar behavior of limestone and can act not only as a filler but it can be an active participant in the hydration of cement, taken up to the system and react with aluminate and ferrite phases [1], accelerating initial cement hydration and influencing hydrate assemblage.

4．Conclusions

1) Concrete recycling by-products can be value-added materials, and the $CaCO_3$ from powder wastes enhanced the hydration kinetics and the mechanical performance of mortar and pastes, by means of filler and chemical effects.
2) The positive effect of $CaCO_3$ combined with GGBS was observed in the ITZ of mortar, when there was unoccupied spaces to be filled by hydration products.

【References】

1) Zelic et al.：The properties of Portland cement-limestone-silica fume mortars, Cement and Concrete Research, Vol.30, Issue 1, pp.145-152(2000)