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Properties of RPC with Calcium Carbonate Concrete Waste Powder

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Abstract. Calcium carbonate concrete is a normally concrete in the area with rich limestone. With the heavy use, a large of Calcium carbonate concrete waste is generated, how to reuse the waste is an important problem. The generation of reactive powder concrete (RPC) with silica fume is relative more expensive than normal concrete. Using the calcium carbonate concrete waste instead of silica fume in RPC can realize the recycling of construction and demolition waste, moreover, the high price of RPC manufacture can be decreased. The study mainly focused on the mechanical properties and durability as well as the microstructure of RPC with calcium carbonate concrete waste powder (CCWP) instead of silica fume, the results confirmed that the mechanical strengths of 3, 7, 28 days of RPC with CCWP did not obviously decrease, freezing and thawing test could attain to 500 recycles without obvious destruction and carbonation did not happen after 28 days. RPC with CCWP had no more amorphous material and good crystallinity, its microstructure was dense as that of RPC without CCWP.

1. Introduction

Reactive powder concrete (RPC) characterized by super-high strength, extreme durability and superior toughness [1], is a type of concrete with high doses of fine-grained cement and a low water–cement ratio, its compressive strengths can attain in the range of 200 ~ 800 MPa, compared with a maximum compressive strength in the range of 50 ~ 100 MPa for high strength concrete (HSC) [2,3], the Chinese standard GB/T 31387 also defines that RPC 100 has a compressive strength with more than 100 MPa [4].

The basic principles for the development of RPC, explained by many researchers, are characterized with no coarse aggregate, high compactness by powder, low water to cement ratio, use of suitable pozzolanic material, superplasticizer and steel fibers, treatment by heat or pressing during curing [5].

RPC can be used in the defense industry, in nuclear power plants, and in weapons factories. In Europe, RPC is also applied to the construction of bridges and viaducts to reduce their cross-sectional areas. In Turkey, RPC is used in the production of manhole covers and storm grates [2]. In China, RPC is used to produced cover plate for high speed railway, 200000 m^3 RPC were used in the construction of high speed railway in 2010, it was the most use in the world [6].

However, because of their ultra- high strengths and high manufacturing costs, the use of RPC has been questioned with concerns raised about possible ultra-brittle failure and unfavorable cost to performance efficiency [1].Silica fume is expensive as 6 ~ 10 times as the price of normal cement in China, therefore, RPC is only employed in restricted areas [2].

Nowadays, more and more concrete waste was accumulated in landfill, 500 Mio. Tons concrete wastes were produced in 2014 in China [7]. Most concrete wastes are difficult to reuse as aggregate to produce new concrete because of lower qualities of recycled concrete aggregate due to presence of residual mortar[8, 9], for this reason, when dealing with concrete recycling, a differentiation between coarse (nominal size > 5 mm) and fine aggregates (maximum size < 5 mm) is generally done. Coarse recycled concrete aggregates are commonly used in partial replacement of natural aggregates in concrete, however, the concrete mix design has to be adjusted in order to correct the worsening of final properties such as workability and durability, especially in respect to alkali – silica reaction, corrosion (due to chloride content) and freeze thaw resistance. On the contrary, fine recycled concrete aggregates are less useful as aggregates in concrete as they can be highly detrimental for what concern strength, workability and durability [10]. Therefore, at present, recycling industry has a very limited interest in fine concrete waste, even if they account at least for about the 30% of the entire building material waste [11].

Silica fume, a kind of pozzolanic material is used in RPC as a fine aggregate to play a micro filling role in no heat curing, however, because of the high price, silica fume is normally replaced by other pozzolanic material [12]. Limestone powder with the most content of calcium carbonate has low reactivity and is primarily used as a filler material [13-15]. The calcium carbonate concrete waste powder (CCWP) contains a lot of calcium carbonate and has reactivity material because of the rest cement without hydration [16], probably, CCWP has the same function in RPC like silica fume. Some studies certified that concrete waste powder had activity and could be used in Mortar replacing of 20% cement [17]. This study investigated the properties of RPC with CCWP instead of Silica fume in order to decrease the use quantity of silica fume.

2. Experimental Materials and Method

2.1 Experimental materials

CCWP was made from a mass concrete with the aggregate of calcium carbonate, derived from a demolition site in China. CCWP was generated by the following methods:

- Direct generated grade (< 0.08 mm) by crushing,
- Grade (< 0.08 mm) after grinding the concrete waste grades more than 0.08 mm in ball mill.

The chemical elements of CCWP mainly contain CaO, CO_2 and SiO_2 due to the test results in table 1. According to the content CaO, the calculated content of calcium carbonate is about 76.4%.

The mineral composition of CCWP was mainly owned by calcium carbonate, DSC determination results showed that CCWP reacted with absorption heat in the temperature of 800 ℃ due to the decomposition of calcium carbonate (see figure 1).

Table 1. Chemical compositions of CCWP compared to silica fume and cement (%).

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	TiO_2	CO_2
CCWP	12.3	4.1	1.4	42.8	2.5	0.7	0.3	0.9	0.3	34.4
Silica Fume	77.9	0.7	1.6	1.9	2.1	6.4	1.1	1.5	0.1	4.6
Cement [18]	14.0	3.5	1.8	42.5	2.5	0.7	0.1	0.5	0.2	34.5

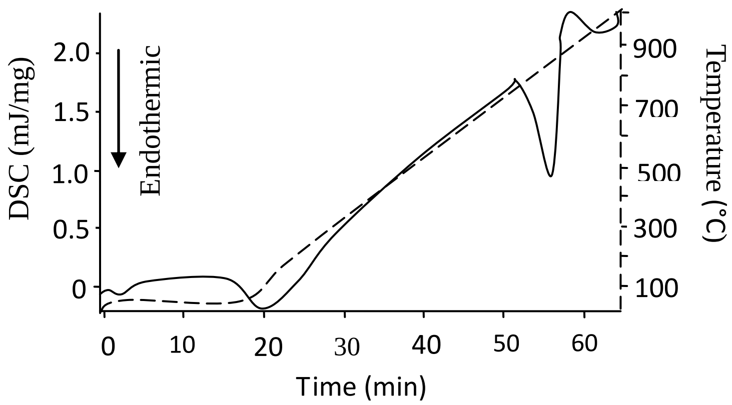

Figure 1. DSC determination for CCWP.

2.2 Experimental method

The test samples for mechanical properties of RPC with CCWP instead of silica fume contained cement, fine sand, silica fume, CCWP, Poly carboxylic acid and water, without steel fiber, the constitutes were detailed determined as follows:

- Cement: Portland cement (P.O 42.5) was manufactured in Shanshui Cement Company of Shandong.
- Silica fume (SF): was bought from Pengcheng silica fume company of Shandong with specific surface area of 20,700 m^2/kg.
- Polycarboxylic acid (PC): was produced by the Huadi of Shandong Company.
- Fine sand (FS): Quartz sand was obtained from the standard sand with maximum nominal sizes of 0.125 mm.

The concept of test samples preparation was listed in table 2, Silica fume in RPC was replaced by CCWP with 15%, 30% and 45%, and samples were cured in 65 ℃ warm water in a thermostat.

Table 2. Concept of RPC for experiments.

	Cement	SF	FS	PC	Water	CCWP	W/C
Reference Sample	1	0.250	1.1	0.018	0.28	0	0.28
Replacement 15%	1	0.213	1.1	0.018	0.28	0.037	0.28
Replacement 30%	1	0.175	1.1	0.018	0.28	0.075	0.28
Replacement 45%	1	0.138	1.1	0.018	0.28	0.112	0.28

Samples of Rectangular columns 40 × 40 ×160 mm for mechanical strengths were made according to the Chinese standard GB/T 17671 [19].The freezing and thawing experiment and carbonation resistance test were carried out with 100 × 100 × 400 mm prisms according to Chinese standard GB/ T50082 [20].

The freezing and thawing experiment was determined the cycles of the samples in a fast freezing and thawing machine according to Chinese standard GB/T50082. The determination process of freezing and thawing depended on two indexes: mass loss (△W, as in equation (1)) and durability index (Pn, as in equation (2)). The freezing thawing test can be finished, when

- The test reaches the required cycles,
- △W > 5%, or
- Pn < 60%.

$$\Delta W = \frac{Wo - Wn}{Wo} \times 100 \tag{1}$$

where,

ΔW = weight change of specimen at n cycles of freezing and thawing in percent in %.

Wo = weight change of specimen at the beginning of the test in Kg.

Wn = weight of specimen after n cycles in Kg.

$$Pn = \frac{f_n^2}{f_o^2} \times 100 \tag{2}$$

where,
P= percentage of relative dynamic modulus of elasticity after n cycles of freezing and thawing in %.
n = number of cycles at the time of testing.
fn = fundamental transverse frequency after n cycles of freezing and thawing in Hz.
fo = fundamental transverse frequency at zero cycles in Hz.

3. Results and Discussion

3.1 Mechanical strengths of RPC with CCWP

The 3, 7 and 28 days flexural and compressive strengths of RPC with CCWP were tested according to the GB/T17671 [19], results were indicated in tables 3 and 4.

Table 3. Flexural strengths of RPC with CCWP (MPa).

Days	Reference (MPa)	Replacement of silica fume with CCWP		
		15%	30%	45%
3	10.90	10.35	10.40	10.15
7	15.05	15.75	14.80	15.95
28	12.75	11.40	11.10	11.75

According to test results, strengths of RPC with CCWP had little difference compared to those of reference, furthermore, the RPC with 45% CCWP instead of silicate fume indicated relatively higher compressive strengths than those of reference. Two obvious results could be come out: because of curing in 65 ℃ warm water, the RPC hydrated very quickly, 3 days compressive strength was 95.73 MPa, and had no big difference compared to 7 days and 28 days values. So far as to the flexural strength, 28 days value was smaller than that of 7 days. The placement of CCWP instead of silicate fume had little influence on the mechanical strength of RPC, especially, RPC with 45% CCWP had relative higher mechanical strengths (see figure 2).

Table 4. Compressive strengths of RPC with CCWP (MPa).

Days	Reference (MPa)	Replacement of silicate fume with CCWP		
		15%	30%	45%
3	95.73	90.98	83.80	91.88
7	95.03	92.68	91.15	95.83
28	111.04	101.01	104.03	113.20

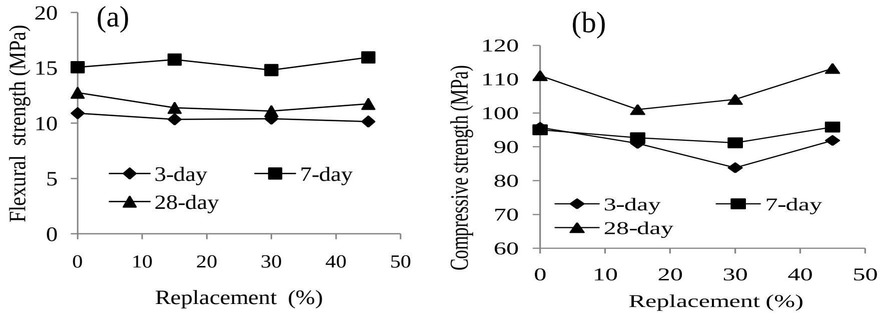

Figure 2. Influence of CCWP content on the flexural strengths (a) and compressive strengths (b) of RPC.

3.2 Results of carbonation resistance and freezing and thawing

The color of the RPC samples with different CCWP contents after 28 days carbonation test was lilac with the treatment of 1% Phenolphthalein, specially, the edge color did not obviously changed. Results showed that the samples did not be carbonized in the carbonation box after 28 days. RPC had dense structures, which was not changed with the addition of CCWP.

Freezing and thawing tests of RPC were determined until to 500 circles, results showed that all △W values were not more than 5%, all Pn values were not less than 60 % (see table 5). According to the tested data, the results could be confirmed that the samples of RPC with CCWP were not damaged after 500 cycles, which attained to the requirement of RPC Chinese standard GB/T 31387-2015.

3.3 Microstructures of RPC with CCWP

The crystal ingredient and microstructures of reference and RPC with CCWP instead of 45% SF were determined by the tests XRD and SEM. XRD determination Results showed that reference sample had amorphous materials and relative bad crystallinity, the amorphous material was active ingredients in silica fume , that meant silica fume in RPC did not completely take place the pozzolanic reaction. By contrast, the XRD photograph showed RPC with CCWP instead of 45 % SF had tiny amorphous materials and good crystallinity (Figures 3 and 4). The SEM test pictures showed that the microstructures had no obvious difference between reference and RPC with CCWP (Figure 5), they were both dense.

Table 5. Results of freezing and thawing of RPC with CCWP.

Cycles	Index	Replacement of CCCWP instead of silicate fume			
		0	15%	30%	45%
0	Wo (kg)	8.624	8.598	8.712	8.688
	f_o^2 (GPa)	4895807	4879682	5047069	4975143
100	△W (%)	0.46	0	0	0.88
	Pn (%)	96.54	100	94.34	100
200	△W (%)	1.27	0	1.29	1.30
	Pn (%)	96.11	100	100	100
300	△W (%)	0.20	1.30	0.61	0.12
	Pn (%)	96.90	100	100	100
400	△W (%)	0.98	1.68	2.34	2.66
	Pn (%)	94.56	95.33	97.69	94.38
500	△W (%)	2.19	3.78	3.56	4.03
	Pn (%)	89.79	87.29	90.24	88.55

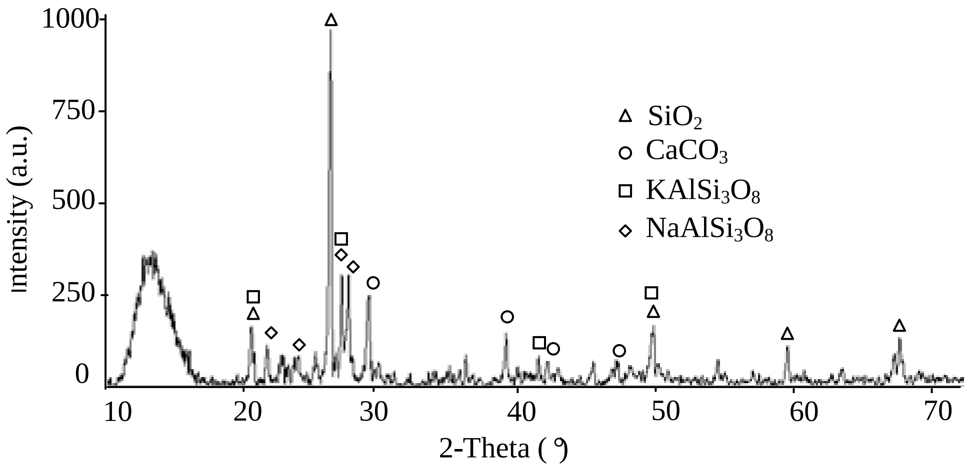

Figure 3. XRD-result for reference sample.

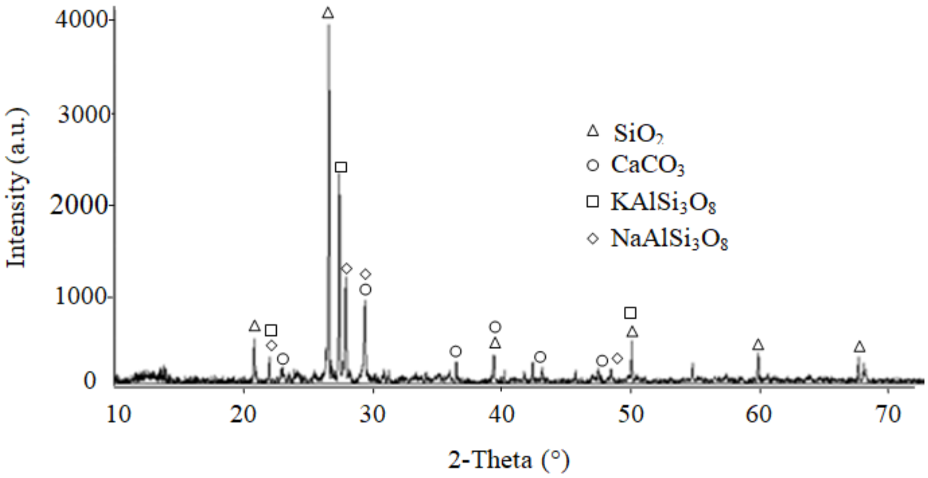

Figure 4. XRD-result for RPC with CCWP instead of 45% SF.

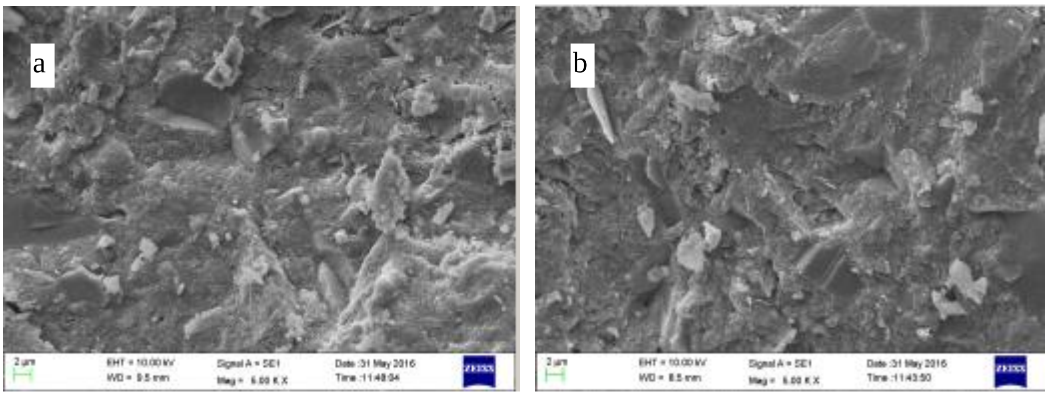

Figure 5. SEM-result for the reference RPC (a) and with CCWP instead of 45% SF (b).

4. Conclusions

This study examined the mechanical strengths, durability of RPC with CCWP instead of silica fume, according to the experiment data, the main conclusions were confirmed as follows:

1) The 3, 7 and 28 days flexural and compressive strengths of RPC with CCWP instead of 15%, 30% and 45% silica fume had no obvious difference with corresponding values of reference sample, the 28 days compressive strength of RPC with 45 % CCWP exceeded 100 MPa.

2) The freezing and thawing test indicated that the RPC with 15%, 30% and 45% CCWP instead of silica fume attained to 500 cycles. The carbonation reaction did not happen in the RPC with CCWP.

3) Silica fume in RPC had no entire pozzolanic reaction, and reference RPC has bad crystallinity, on the contrary, RPC with CCWP had no more amorphous materials and good crystallinity. The microstructure between reference sample and RPC with CCWP had no obvious difference.

5. References

[1] Yia N H, Kim J H J 2012 *Construction and Building Materials* **28** 694–707
[2] Canbaz M 2014 *Construction and Building Materials* **70** 508–13
[3] Zheng W Z, Luo B F, Wang Y, 2013 *Construction and Building Materials* **41** 844–51
[4] GB/T31387 2015 Reactive powder concrete (Beijing: Chinese quality supervision and administration bureau)
[5] Al-Hassani H M, Khalil W I, Danha L S 2014 *ACTA Ehnica Corvinensis-Bulletin of Engineering Tome VII* 47-58
[6] Compilers working group 2013 Explanation for test method of impact resistance super powder concrete (Solicit Opinions Manuscript)
[7] Guo S H 2015 Resource industry development report for 2014 on construction and demolition waste in China (Beijing: Products technology innovation strategic alliances of resourcezation of

IOP Conf. Series: Materials Science and Engineering **371** (2018) 012014 doi:10.1088/1757-899X/371/1/012014

construction and demolition in China)
[8] Sanchez de J M, Gutierrez P A 2009 *Constr. Build. Mater.* **23** 872-79
[9] Sui Y W, Tian Q B, Yue X T et al 2015 Study on influence factors of high quality recycled Concrete aggregates produced by thermal-grinding method. *Journal of Shandong Jianzhu University* **30** 544-49
[10] Zhao Z, Remond S, Damidot D, Xu W 2015 *Construct Build Mater* **81** 179-86
[11] Gastaldi D, Canonico F, Capelli L, Buzzi L, et al. 2015 *Cement & Concrete Composites* **61** 29-35
[12] He F, Yang J P, Ma S F 2007 Effect of Silica Fume Quantity on Performance in Reactive Powder Concrete *Journal of Guilin University of technology* **27** 77-80
[13] Suaiam G, Makul N 2013 *Constr. Build. Mater.* **38** 455-64
[14] Suaiam G, Makul N 2013 J. Clean. Prod. **57** 308-19
[15] Zhang Z Q, Wang Q, Chen H H 2016 *Powder Technology* **301** 16-25
[16] Zhang X, Wu Y S, Zhang J B, He J 2011 The Activity stimulated of construction wasted powder and its reuse feasibility analysis *Jiangxi Science* **29** 70-73
[17] Xu R L 2011 Activation and application of construction waste powders (Wuhan: Dissertation for master degree of Technology University of Hubei)
[18] Locher F W 2000 Zement-Grundlagen der Herstellung und Verwendung (Duesseldorf: Verlag Bau und Technik)
[19] GB/T17671 1999 Method of testing cements-Determination of strength (Beijing: Chinese quality Supervision and Administration Bureau)
[20] GB/T50082 2010 Standard for test method of long-term performance and durability of ordinary concrete (Beijing: Chinese quality supervision and administration bureau)

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