

# Research on Durability of Recycled Ceramic Powder Concrete

M C Chen<sup>1,2,3</sup>, W Fang<sup>1,2</sup>, K C Xu<sup>1,2</sup> and L Xie<sup>1,2</sup>

<sup>1</sup>Jiangxi Provincial Key Laboratory of Simulation and Control of Building Process,

<sup>2</sup>School of Civil Engineering and Architecture, East China Jiaotong University,  
Nanchang 330013, China

Email: 919367042@qq.com; fangweiwei23@163.com; 505958373@qq.com;  
boshini@163.com;

**Abstract.** Ceramic was ground into powder with 325 mesh and used to prepare for concrete. Basic mechanical properties, carbonation and chloride ion penetration of the concrete tests were conducted. In addition, 6-hour electric fluxes of recycled ceramic powder concrete were measured under loading. The results showed that the age strength of ceramics powder concrete is higher than that of the ordinary concrete and the fly ash concrete. The ceramic powder used as admixture would reduce the strength of concrete under no consideration of its impact factor; under consideration of the impact factor for ceramic powder as admixture, the carbonation resistance of ceramic powder concrete was significantly improved, and the 28 day carbonation depth of the ceramic powder concrete was only 31.5% of ordinary concrete. The anti-chloride-permeability of recycled ceramic powder concrete was excellent.

## 1. Introduction

Waste ceramic is a new renewable material. It is famous for its light weight, low price, high pozzolanic reactivity and rich source of SiO<sub>2</sub>. Waste ceramic as construction materials has been widely applied for various practical engineering and got remarkable economic and social effects. In the past few decades, many domestic and foreign scholars did researches on the utilization of ceramics in cement and concrete industry, and obtained a large number of reliable data and useful conclusions with waste ceramic as coarse aggregates, fine aggregates and admixtures in concrete. The various performance of that recycled ceramic concrete was analysed [1-6]. The existing researches has shown that crushed ceramic as coarse aggregates has a certain effects on the performance of the recycled concrete, but the treatment of ceramic coarse aggregates can meet the requirements of concrete strength[7-8]. Previous studies have shown that waste ceramic used as regenerated ceramic sand in concrete can improve effectively mechanical properties of the concrete [9-10]. As Wang [6] indicated polished ceramic brick dust as admixtures has better pozzolanic reactivity; the SiO<sub>2</sub> in the brick dust has strong activity to participate in chemical reactions than fly ash does. In summary, waste ceramic used as parts of recycled concrete were feasible and practicable.

In the experimental study of ceramic recycled concrete, most scholars have devoted to using waste ceramic as coarse and fine aggregates. There are very few researches on employing waste ceramic powder as admixtures, especially on the analysis of its recycled concrete durability [11-13].



The author's previous researches showed that the optimal amount of ceramic powder as admixture is 25%, and the age strength growth curve of its recycled ceramic cement mortar is similar to that of fly ash. Therefore, in present paper, ceramic powder of 25% will be used to investigate the basic mechanical properties, carbonization and anti-chloride-permeability performances, which provides a theoretical basis for developing and popularizing ceramic powder concrete.

## 2. Materials and methods

### 2.1. Materials

The waste ceramic of apparent density  $2.375 \text{ kg/m}^3$  was collected from the Jiangxi provincial Jingdezhen. Table 1 shows the chemical compositions of ceramic. The specific surface area of ceramic powder is  $458 \text{ m}^2/\text{kg}$ . The grain size distribution of ceramic powder is shown in Table 2.

**Table 1.** The chemical compositions of ceramic (unit: %).

SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	SO <sub>3</sub>
62.72	23.31	1.24	6.67	0.65	1.55	0.96	0.07

**Table 2.** Particle size distribution of ceramic powder.

grain composition ( $\mu\text{m}$ )	<10	10~20	20~30	30~60	>60
percentage (%)	51.0	20.4	11.1	9.5	8.0

### 2.2. Concrete production

C40 concrete test specimens consisted of 5 groups. There are 12 specimens in each group. Tests of their compression, carbonation resistance and chloride permeability were performed. Mix proportion of the concrete was designed according to "Specification for mix proportion design of ordinary concrete"(China standard specification: JGJ 55-2011). OC is ordinary concrete, CC-1 and FC-1 indicate concrete made from ordinary concrete whose 25% cement is replaced by recycled ceramic and fly ash, respectively. CC-2 and FC-2 are respectively concrete based on CC-1 and FC-1 whose influence coefficients of admixture were chosen to be 0.8 by virtue of the specification. The mixture ratio of concrete shown in Table 3.

**Table 3.** Mix proportions of concrete (unit:  $\text{kg/m}^3$ ).

No.	Strength grade ( $F_{cu}$ )	Cement	Fly ash	Ceramic powder	Sand	Coarse aggregate	Water
<b>OC</b>	C40	381.11	0	0	591.57	1201.07	186.30
<b>CC-1</b>	C40	285.836	0	95.278	567.48	1152.15	186.30
<b>FC-1</b>	C40	285.836	95.278	0	567.48	1152.15	186.30
<b>CC-2</b>	C40	350.30	0	116.77	567.48	1152.15	186.30
<b>FC-2</b>	C40	350.30	116.77	0	567.48	1152.15	186.30

### 2.3. Test procedure

The compressive strength of concrete specimens was respectively measured at 3d, 7d, 14d, 28d and 56d.

The depth of carbonation of specimens were measured after carbonized for 3d, 7d, 14d and 28d. The carbonation tests were conducted with TH-074 concrete carbonation machine based on 'standards for test method of long-term performance and durability of ordinary concrete '(China standard: GB/T 50082-2009). Variations of the quality and relative dynamic elastic modulus for post-carbonated test

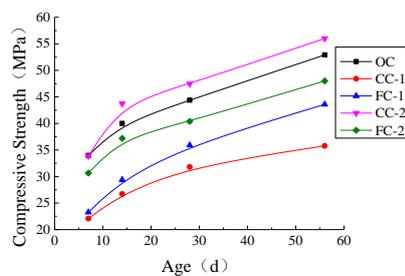
specimens were analyzed to prove present recycled ceramic powder concrete to be sufficient in resisting carbonation.

The chloride diffusion coefficient of concrete was measured by electric flux method through RCM-F concrete durability machine. The chloride ion penetration tests were carried out by standard ASTM C2012 and China standard GB/T 50082-2009.

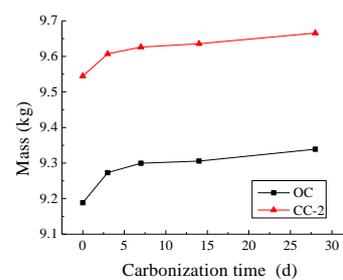
### 3. Text results and analysis

#### 3.1. Compressive strength

It can be seen from Figure 1 that growth trends of age strengths of all concrete specimens are similar. The 28d compressive strength of CC-1 is the lowest, 31.80Mpa; that of CC-2 is the highest, 47.45Mpa, which increase by 6.9%, 49.2%, 32.1% and 40.4% by comparison of those of OC, CC-1, FC-1 and FC-2, respectively. It means that the decrease of the influence coefficients of admixture for CC-2 is helpful to increase its compressive strength, and its growth rate is greater than those of the other cases. Therefore, in the following CC-2 material is used to study the durability of recycled ceramic powder concrete.



**Figure 1.** The age strength of five groups concrete.



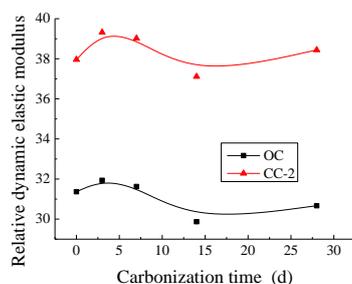
**Figure 2.** Change in mass.

#### 3.2. Carbonation resistance

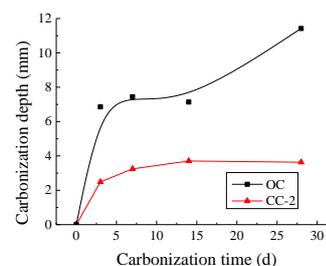
Carbonation test of CC-2 material was conducted to investigate the impact of carbonation on its mass and relative dynamic elastic modulus. All experimental data are graphed in Figures 2-4 For the sake of comparison, relevant experiment data for OC material is also given in the figures.

It is shown from Figure 2 that all curves rise quickly in the first 3 days of carbonization, and then become stable with increasing carbonization time; apparent mass of CC-2 is greater than that of OC, implying that the recycled ceramic powder concrete is more denser.

At the early stage of carbonization, moisture absorption by pore structure in concrete is the mainly reason of quality variation. Absorption saturated and calcium carbonate filler in capillary resulting in the absorption of moisture difficult, the quality in later period increases slightly.



**Figure 3.** Change in relative dynamic elastic modulus.

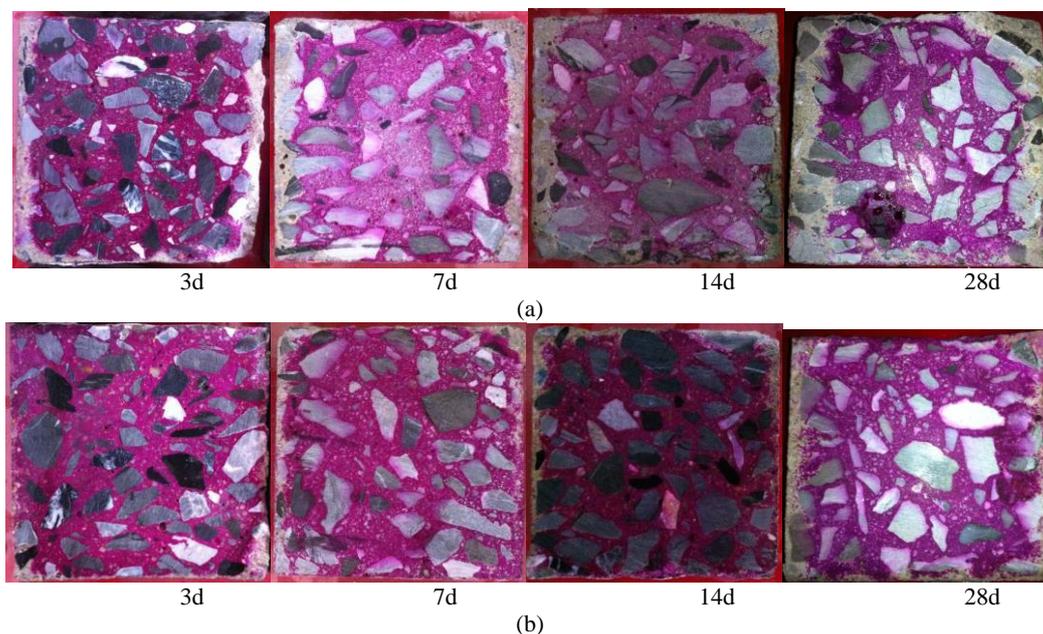


**Figure 4.** Carbonation depth changes with time.

Figure 3 shows relationships between relative dynamic elastic modulus and carbonization time. From this Figure, we can draw similar conclusions to those from Figure 2. In general, 2 curves in Figure 3 comply with a trend of up-down-up.

The age strength of the concrete is still developing in the early phase of carbonation, and the concrete structures are becoming more dense for hydration and carbonation reactions. Therefore, its relative dynamic elastic modulus have a certain increase. Thereafter, since the alkalinity of concrete pore solution and concrete matrix decrease in the carbonation reaction process, the concrete generates shrinkage, and thus leading to the decrease of its relative dynamic elastic modulus. During the later phase of carbonation, compounds resulting from the carbonation are filled in microcracks and pores in concrete structure, which gives rise to denser concrete microstructures, and therefore the concrete relative dynamic elastic modulus increases

Figure 4 shows the carbonization depth of OC and CC-2 against carbonation time. It can be seen that the carbonation depth of CC-2 is only 3.6 mm while the OC already among 11.4mm at 28 day carbonation. Pozzolanicity and micro-aggregate effects produce when ceramic powder is added into concrete. The microstructure of concrete filled with ceramic powder forbids the invasion and diffusion of carbon dioxide in the concrete. Furthermore, pores in concrete structure is filled with calcium carbonate from the carbonation reaction to prevent carbon dioxide from diffusing further in the concrete. As carbonation time increase, the carbonation progresses gradually. Due to reasons aforementioned, we can draw a conclusion that ceramic powder used as admixtures is helpful to improve the carbonation resistance of concrete. Figure 5 presents experimental photos of carbonation for OC and CC-2. Comparison of Figure 5(a) with 5(b) indicates CC-2 has stronger carbonation resistance than OC does.



**Figure 5.** Photos of carbonation (a) OC; (b) CC-2.

### 3.3. Anti-chloride-permeability

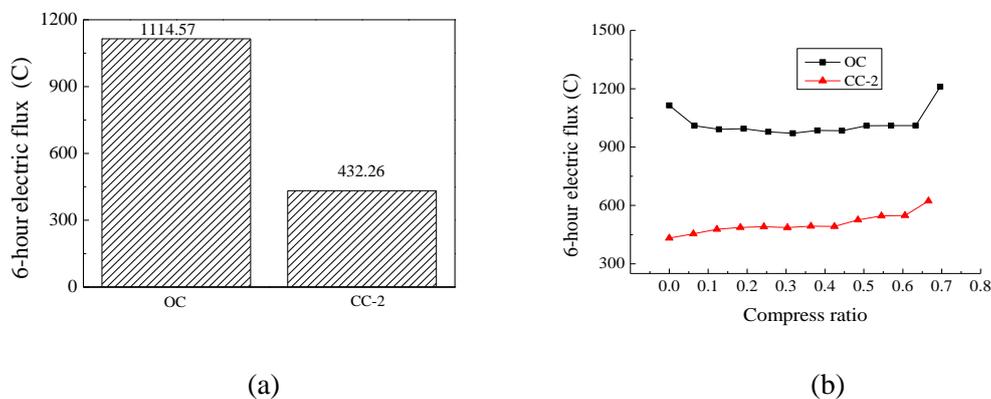
As the corrosion of reinforcements in concrete is mainly induced by the attack of chloride ions, the effects of ceramic powder on chloride ion penetration were studied. 6-hour electric fluxes of ceramic powder concrete were measured. The standard of chloride ion permeability in concrete shown in Table 4.

It can see from Figure 6(a) that 6-hours electric flux of OC increased 58.99% than its of CC-2, implying that the resistance of chloride ion permeability of CC-2 is higher than that of OC. From

Table 5 and Figure 6(a) we can conclude that the classification of anti-chloride-permeability of OC belongs to C, but that of CC-2 E, which is excellent in anti-chloride-permeability.

**Table 4.** Relations of 6-hours electric flux and chloride ion permeability in concrete.

6-hour electric flux (C)	Levels of durability of concrete	Chloride ion permeability	Classify
>4000	poor	high	A
2000~4000	weak	medium	B
1000~2000	average	low	C
500~1000	good	very low	D
<500	excellent	negligible	E



**Figure 6.** 6-hours electric flux of OC and CC-2 (a) no stress; (b) loading.

It is shown from Figure 6(b) that, for OC, 6-hour electric flux of concrete decreases when compress ratio is small, which may be the compactness of concrete microstructures by the compress at initial stage, and then keep stable growth until compress ratio reaches 0.63. Afterward, it increase quickly; for CC-2, 6-hour electric flux grows stably until compress ratio reaches 0.61 and then increase quickly but relatively slower than OC does. When compress ratio is higher, the reason why the growth of 6-hour electric flux is rapid is that the higher compress ratio accelerate concrete damages. Comparison of OC curve with CC-2 curve in Figure 6(b) shows it is stronger in electric flux for CC-2 than for OC, representing that ceramic powder used as admixtures can effectively decrease the chloride ion permeability of concrete. Summation of section 3.2 and 3.3 tells us a fact that ceramic powder used as admixtures can improve durability of recycled ceramic powder concrete.

#### 4. Conclusion

1. Ceramic powder as admixtures can effectively improve the compressive strength of concrete. Under the same conditions, the basic mechanical properties of ceramic powder concrete are better than that of fly ash concrete.
2. Rational addition of ceramic powder can effectively improve the carbonization resistance and anti-chloride-permeability of concrete.
3. In actual mix proportion design of recycled ceramic powder concrete can refer to that of fly ash concrete whose influence factor is 0.8 given in the Specification.

#### 5. Reference

- [1] Liu F L, Liu J H, Ma B G, Huang J and Li H N. 2015 Basic Properties of Concrete Incorporating Recycled Ceramic Aggregate and Ultra-fine Sand *Journal of Wuhan University of Technology-Mater.* **30(2)** 352–60
- [2] Guerra I, Vivar I, Llamas B, Juan A and Moran J. 2009 Eco-efficient Concretes: the Effects of Using Recycled Ceramic Material from Sanitary Installations on the Mechanical Properties of Concrete *Waste Management.* **29(2)** 643–6
- [3] Halicka A, Ogrodnik P and Zegardlo B. 2013 Using Ceramic Sanitary Ware Waste as Concrete Aggregate *Construction and Building Materials.* **48(11)** 295–305
- [4] Medina C, Sánchez de Rojas M I and Frías M. 2013 Properties of Recycled Ceramic Aggregate Concretes: Water Resistance *Cement and Concrete Composites.* **40(40)** 21–9
- [5] Jiménez J R, Ayuso J, López M, Fernández J M and Brito J D. 2013 Use of fine recycled aggregates from ceramic waste in masonry mortar manufacturing *Construction and Building Materials.* **40** 679–90
- [6] Wang G X. 2010 Pozzolanic Activity of Ceramic Polishing Powder as Supplementary Cementitious Material *Journal of the Chinese Ceramic Society.* **38(7)** 1229–34
- [7] Chen M C, Ding X M, Wang K and Xie L. 2012 Research on Recycled Building Ceramic Concrete *Materials Review.* **26** 303–6
- [8] Xu K C, Fang W, Chen M C and Ding X M. 2014 On the Mechanical Properties of Ceramic Recycled Coarse Aggregate Concrete *Journal of Experimental Mechanics.* **29(4)** 478–80
- [9] Silva J, Brito J D and Veiga R. 2008 Fine Ceramics Replacing Cement in Mortars Partial Replacement of Cement with Fine Ceramics in Rendering Mortars *Materials and Structures.* **41(8)** 1333–44
- [10] Zhang C Z, Liu F L and Liu J H. 2011 Research on the Impact of Waste Ceramic Reclaimed Sand Mortar Performance *China Concrete and Cement Products.* **7** 54–7
- [11] Medina C, Sánchez de Rojas M I and Frías M. 2013 Freeze-thaw Durability of Recycled Concrete Containing Ceramic Aggregate *Journal of Cleaner Production.* **40(2)** 151–60
- [12] Cheng Y H, Huang F, Li G L, Xu L S and Hou J L. 2014 Test Research on Effects of Ceramic Polishing Powder on Carbonation and Sulphate-corrosion Resistance of Concrete *Construction and Building Materials.* **55(2)** 440–6
- [13] Kulovan áT, Vejmelkov áE, Keppert M, Rovnan kov áP, Keršneret Z and Cern ýRobert. 2016 Mechanical, durability and hygrothermal properties of concrete produced using Portland cement-ceramic powder blends *Structural Concrete.* **17(1)** 105–15