Study on Recycled Concrete Powders as Mineral Admixture in Recycled Concrete

Xi Chen, Ying Li*, Xiaoming Kang, Yaohu Fan

School of Civil Engineering, Qinghai University, Xining, Qinghai Province, 810000, China.

*Corresponding author’s e-mail: liying.qh@163.com

Abstract. The process of recycling waste concrete generated fine powders with a particle size of less than 0.16 mm; it contains a large amount of hardened cement and unhydrated cement and has high activity. In order to meet the requirement of sustainable development in concrete industry, this study aims to improve the recycle use level of these fine powders in concrete. First, the properties of the recycled concrete powder were analyzed, and compared with one normal mineral admixture such as fly ash. Then the workability and compressive strength test of the concrete which mixed by different replacement ratio of the recycled concrete powder and fly ash were performed. The results show that the the content of SiO$_2$ in recycled concrete powder is more than cement and fly ash. The replacement rate of RCP has little influence on the slump of fresh recycled concrete compared to fly ash. When the replacement rate of the recycled concrete powder is 20%, the compressive strength of corresponding concrete at each age is close to that of control concrete, especially at 56d, the compressive strength of concrete reach to 90% of that of control concrete. So the application of the recycled concrete powder can save cement and has certain environmental and economic benefits.

1. Introduction

In recent years, with the expansion of urban construction activities, more and more construction waste were generated, so the use of waste concrete to prepare recycled aggregates has attracted worldwide attention in view to its many social and environmental benefits [1]. The use of recycled aggregates can not only reduce the secondary pollution of construction waste to the environment, but also alleviate the practical problems of the current shortage of natural aggregates faced by the concrete industry. Nowadays, only a small fraction of them is recycled in the manufacture of concrete and mortar. If these waste concrete can be used in large quantities, pollution will be greatly reduced[2].

A large number of studies[3-8] showed that the process of recycling waste concrete generated dust with a particle size less than 0.16 mm, which accounts for about 5% ~ 10% of the total weight of waste concrete, calling recycled concrete powders( Abbreviated as RCP). It contains a large amount of hardened cement and cement that is not fully hydrated and has higher activity. At present, the recycled fine powder is more used as a mineral admixture instead of cement added to the mortar or concrete[9-10], utilization of the RCP as mineral admixture in concrete can reduce the pollution of the RCP particles to the environment, and also reduce the need for consumption of natural resources required to produce cement or concrete.

This paper presents the results of investigations about properties of RCP and FA, also describes the results of a study aimed at comparing the effects of the replacement rate of RCP and FA on the
workability and compressive strength of concrete separately by varying the content of RCP and FA from 0% to 40%.

2. Materials and methods

2.1 Experimental Materials
Cement (CE): P•O 42.5 ordinary Portland cement in Qinghai Datong Cement Plant;
Recycled concrete powders (RCP): The fine particles with a particle size less than 0.16 mm are collected during the process of crushing and recycling the construction waste. For comparison, a coal fly ash (FA) were also considered.

The chemical composition and performance indicators of these materials are shown in Table 1 and Table 2. The particle size distribution is shown in Fig 1.

| Materials | SiO$_2$  | CaO   | Al$_2$O$_3$ | MgO | Fe$_2$O$_3$ | SO$_3$ |
|-----------|---------|-------|-------------|-----|-------------|--------|
| CE        | 19.8    | 40.4  | 7.67        | 2.06| 2.66        | 2.31   |
| RCP       | 27.8    | 29.1  | 6.70        | 4.49| 2.73        | 1.11   |
| FA        | 21.5    | 1.27  | 15.2        | 0.40| 1.36        | 0.24   |

| Materials | Bulk density (Kg/m$^3$) | Apparent density (Kg/m$^3$) | Specific surface area (m$^2$/Kg) |
|-----------|-------------------------|-----------------------------|---------------------------------|
| CE        | 1056                    | 2978                        | 493                             |
| RCP       | 856                     | 2355                        | 467                             |
| FA        | 1245                    | 1919                        | 438                             |

2.2 Mixture proportions design
To investigate the influence of replacement rate of RCP content on the properties of recycled concrete, five different RCP for Portland cement replacement ratios of 0%, 10%, 20%, 30% and 40% were investigated. The mix proportions are shown in Table 3.

![Fig 1. Particles size distribution of materials](image-url)
Table 3. Mix proportion of the concrete mixtures

| NO.  | w/b | CE (Kg) | RCP (Kg) | FA (Kg) | aggregates (Kg) | Sand (Kg) |
|------|-----|---------|----------|---------|-----------------|-----------|
| RFC-0 | 0.45 | 455     | 0        | 0       | 1032            | 595       |
| RFC-1 | 0.45 | 410     | 46       | 0       | 1032            | 595       |
| RFC-2 | 0.45 | 364     | 91       | 0       | 1032            | 595       |
| RFC-3 | 0.45 | 319     | 137      | 0       | 1032            | 595       |
| RFC-4 | 0.45 | 273     | 182      | 0       | 1032            | 595       |
| RFC-5 | 0.45 | 410     | 0        | 46      | 1032            | 595       |
| RFC-6 | 0.45 | 364     | 0        | 91      | 1032            | 595       |
| RFC-7 | 0.45 | 319     | 0        | 137     | 1032            | 595       |
| RFC-8 | 0.45 | 273     | 0        | 182     | 1032            | 595       |

2.3 Test method
According to GB/T50081-2002[11], the influence of the replacement rate on the workability and compressive strength of concrete were tested. Nine groups of 100 mm × 100 mm × 100 mm cubic specimens were designed in the test. Before testing, specimens were kept 24h under (20±2)℃ and cured in water at (20±1)℃ and relative humidity was above 90%. The tests are conducted at different test ages of 7, 14, 28, and 56 days.

3. Results and discussion

3.1 Properties of RCP
The chemical compositions of RCP are shown in Table1, the content of SiO2 is more than CE and FA, and the RCP has more CaO content too, while CaO and SiO2 are the cement main ingredients. It can be seen that the RCP to be used as a mineral admixture in concrete is theoretically feasible. Table 2 shows that the bulk density of RCP is minimal compared with CE and FA, the apparent density of RCP is smaller than that of CE and larger than that of FA. The specific surface area of RCP is close to that of CE. It can be seen from Fig 1, the particle size distribution of the RCP and FA is not uniform, the FA is coarser than cement and RCP. In addition, the particle size distribution of RCP is more closely to CE than that of FA. The content of particles smaller than 10μm in RCP is more than that of FA, it may have some benefit to improve microstructure of concrete if mixed into concrete as mineral admixture.

3.2 Workability
As shown in Fig 2, the replacement rate of RCP has little influence on the slump of fresh recycled concrete, this due to the activity of RCP is lower than CE, when the amount of cementitious material is constant, as the amount of RCP increases, the amount of cement decreases, so the amount of water required for hydration at an early stage also decreases, so the slump of the concrete changes very little. In contrast, the slump of concrete with the same replacement rate of FA is increased shows that the amount of fly ash can promotes the workability of concrete.
The slump of mixtures with 40% RCP powder decreased 17.9% when compared with the samples with the same replacement rate of FA. This can be explained by the results of scanning electron microscopy of RCP and FA in Fig 3. The surface of the RCP is rougher, while the spherical glass body in fly ash helps to improve the fluidity in the concrete mixing, which has a favorable effect on the workability of the concrete.

![Fig 2. The slump of concrete](image)

3.3 Compressive Strength
The compressive strength can be seen from Fig 4 to Fig 7, which presents that with the replacement rate of RCP or FA increased, the compressive strength of concrete decreased gradually at any age, but as the hydration age increases, the gap between the strengths is gradually narrowing. When the replacement rate is 10%, the compressive strength of concrete with FA is higher than that of concrete with RCP at any age. When the content is more than 10%, the strength development of fly ash concrete shows a downward trend, while the strength of RCP concrete shows a trend of first rising and then falling. Furthermore, when the replacement rate of RCP is 20%, the compressive strength of corresponding concrete at each age is close to that of control concrete, especially at 56d, the compressive strength of concrete with 20% RCP reach to 50.92MPa, is about 90% of that of control concrete. This means that when the replacement rate of RCP is no more than 20%, the RCP has no negative influence on the strength of concrete. Because the content of CaO and SiO$_2$ in RCP in this study is 56.9%, while these two oxides are the main active ingredient in cementitious materials[12], so when the replacement rate of RCP is lower than 20%, the active ingredient in RCP can promote the reaction to form C-S-H gel which can increase the strength of the concrete[13-14]. Also the fine particles in RCP can improve the particle gradation of the cementitious material, the pores in the cement paste are filled, and the compactness of concrete is improved. However, since the activity of the RCP is relatively lower than cement, when the total amount of cementitious materials is constant, the amount of cement will decrease too much with the amount of RCP increased more than 20%, and the strength of concrete will decrease

![Fig 3. Microstructure of materials](image)
significantly.

Conversely, with the replacement rate increased, the compressive strength of concrete with FA decreases obviously at early age, but with hydration time increases, the decrease rate is slowly. When at 56d, the compressive strength of concrete with RCP or FA is very closely at any replacement rate. Due to the low CaO content of FA in this study, so the activity of FA is low too. When the FA mixed into concrete, the early age strength decreased significantly. But the FA contains active silica and alumina, it can be secondary hydrated with calcium hydroxide in the cement hydration product, so that the larger Ca(OH)$_2$ crystal content in the concrete significantly reduced, and the structure in the aggregate interface transition layer improved, so the later age strength of concrete with FA increased significantly.

4.Conclusions

The contents of SiO$_2$ and CaO in studied RCP reach to 56.9%, while these two oxides are the main active ingredient in cementitious materials, so the RCP to be used as a mineral admixture in concrete is theoretically feasible.

The particle size distribution of the RCP and FA is not uniform, the FA is coarser than cement and RCP.

The replacement rate of RCP has little influence on the slump of fresh recycled concrete. The slump of concrete with the same replacement rate of FA is increased shows that the amount of fly ash can promotes the workability of concrete.

With the replacement rate of RCP or FA increased, the compressive strength of concrete decreased gradually at any age, but as the hydration age increases, the gap between the strengths is gradually
narrowing. When the replacement rate of RCP is no more than 20%, the mix of RCP in concrete has no negative influence on the strength of concrete especially at later age. The compressive strength of concrete with FA decreases obviously at early age, but the decrease rate is slowly with hydration time increases. When at 56d, the compressive strength of response to reviewers’ comments concrete with RCP or FA is very closely at any replacement rate.

Acknowledgements
This research was supported by National Natural Science Foundation of China (51668052) and Qinghai Provincial Science and Technology Department Technology Basic Condition platform Project (2018-ZJ-T01)

References
[1] Bin Lei. Durability of recycled aggregate concrete under coupling mechanical loading and freeze-thaw cycle in salt-solution [J]. Construction and Building Materials 163(2018) :840–849
[2] Zengfeng Zhao. Influence of fine recycled concrete aggregates on the properties of mortars [J]. Construction and Building Materials 81 (2015) :179–186
[3] Xue Chen, Qiuyi Li, Xiangning Yang, et al. Properties and application of recycled micropowder [J]. Journal of Qingdao University of Technology, 2013, 34(3) :17-21.
[4] Shengcai Zhang, Ou Geng, et al. Compressive strength and activation of recycled micropowder concrete [J]. Concrete, 2015,11
[5] Qin He, Xi Xie, et al. Recovery and application technology of waste concrete at China and abroad [J]. New Building Materials, 2013 (10) : 38-40.
[6] Hongbing Zhu, Yao Zhao, et al. Research status and suggestions on recycled concrete [J]. Highway Engineering,2013 (1) :98-101.
[7] Yan Sun, Kewei Sun, et al. Research on utilization status and performance of recycled concrete [J]. Concrete, 2010( 3) :105–107.
[8] Feng Shi, Lizhong Ning, et al. Comprehensive utilization of construction solid waste resources [J]. Journal of Water Resources and Water Engineering, 2007, 18( 5) :39-41.
[9] Xinqi Mao, Wenjun Qi, Peng Zhu. Current Research Status of Construction Waste Reclaimed Micropowder[J]. CHINA Concrete and Cement Products , 2015, (8): 89-92.
[10] Ricardo Serpell, Mauricio Lopez. Properties of mortars produced with reactivated cementitious materials[J]. Cement & Concrete Composites, 2015, 64: 16-26
[11] GB/T50081-2002, Standard test method for mechanical properties of ordinary concrete[S].
[12] Liu Yin, Lu Chang, Zhang Haoqiang, et al. Experimental Research on Cementitious Property of Renewable Powders of Construction Waste[J]. China Powder Science and Technology, 2015, 21(5) :33–36.
[13] Yu Linfeng. Experimental study on action mechanism of recycled powder in cement[J]. Construction and Building Materials,2017,(7):108–111.
[14] Zhou wenjuan, Ji zhiyuan, Zhao lei, et al. The basic material properties of construction waste recycled powder and its influence on the performance of cement mortar[J]. China Concrete and Cement Products, 2019,(3): 93–96.