Influence of CWCPM on Strength and Anti-Permeability of Concrete

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ABSTRACT: One way for utilizing construction waste brick is to synthesize construction waste composite powder materials (CWCPM) by mixing construction waste brick powder together with industrial residues and activators. This paper studied the mechanical performance and anti-permeability performance of C25 concrete constructed with CWCPM. Also studied the micro-structures of the C25 concrete via XRD (X-Ray Diffraction) test, analyzed the improvement mechanism of CWCPM to concrete strength and anti-permeability performance. The results show that the dosage of CWCPM has large impacts on the mechanical performances of the C25 concrete, and the CWCPM can improve the concrete’s anti-permeability performance by perfecting hydration products and pore structures. The best performances are obtained at CWCPM dosage of 30%.

KEYWORDS: construction waste composite powder materials; C25 concrete; mechanical performance; anti-permeability performance; microcosmic improvement mechanism

INTRODUCTION

With the rapid development of urbanization, the accumulated quantity of construction wastes in China increases rapidly¹. It has become one of the main problems faced by modern cities² since the construction wastes not only pollute the environment, but also do harm to human health as well as occupy a lot of lands. The construction waste bricks account for about 40% of the total amount of construction wastes, and their annual output is up to 52 million tons. With further developments of economy and technology in China, this figure will continue to increase. Therefore, how to reuse the construction waste bricks is a pressing issue³.

At present, researches related to recycling waste brick are mainly concentrated on the preparation of recycled coarse, fine aggregates and on the production of wall materials, cement⁴⁻⁷, etc. Results indicated that the performance of concrete with recycled waste brick aggregates was very poor. The strength, modulus of elasticity and shrinkage performance of concrete decreased with increasing content of recycled aggregates⁸⁻⁹. Therefore, using waste bricks as aggregates has not been widely employed. In addition, utilizing waste bricks to produce cement requires secondary heating process, which demands a lot of resources and energy. In general, the regeneration utilization rate of waste brick is less than 5% because of its low strength, low activity, large water absorption rate and so on. Therefore, new ways for recycling waste bricks should be looked for.

The low activity and thus the reuse rate of the waste bricks can be improved by compounding the waste brick powder with other industrial residues to form construction
waste composite powder materials (CWCPM). This paper investigated the mechanical strengths and anti-permeability performance of C25 concrete mixed with CWCPM. The results can provide good guidance for finding effective ways for reutilizing construction waster bricks.

1 MATERIALS AND EXPERIMENTAL SCHEME

1.1 Materials

Cement: 42.5 ordinary Portland cement, the apparent density is 3.112g/cm$^3$; coarse aggregate: crushed stone; fine aggregate: ordinary river sand, the fineness modulus is 2.48; water: tap water. The waste brick powder used in this paper was fine grinded with specific surface area of 450 $\text{m}^2/\text{kg}$. The CWCPM was composed by 25% brick powder, 50% slag, 25% fly ash and alkali-activator. The slag and fly ash were in line with the requirements of the “Concrete mineral admixture material application of technical regulations GB / T 51003-2014”.

Tables 1 and 2 show the physical properties and chemical composition of the CWCPM respectively. Figure 1 shows the SEM results of the CWCPM.

<table>
<thead>
<tr>
<th>Standard consistency water (%)</th>
<th>Loss on Ignition (%)</th>
<th>Density (kg/m$^3$)</th>
<th>Specific surface area (m$^2$/kg)</th>
<th>Particle size (um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.285</td>
<td>4.22</td>
<td>2.82</td>
<td>415</td>
<td>8~16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Components</th>
<th>CaO</th>
<th>Al$_2$O$_3$</th>
<th>Fe$_2$O$_3$</th>
<th>SiO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content (wt%)</td>
<td>21.7~25.5</td>
<td>15.8~18.5</td>
<td>2.6~4</td>
<td>42.5~37.5</td>
</tr>
</tbody>
</table>

From the table 1 and 2 we know that the CWCPM has a specific surface area of 415 $\text{m}^2/\text{kg}$ which is larger than the surface area of cement (311 $\text{m}^2/\text{kg}$), and contains...
significant amount of CaO of 21.7~25.5%, means a reasonable chemical composition.

Fig.1 illustrate that CWCPM owns a reasonable particle size distribution and its particles are mainly round and subround and contains a considerable amount of tiny beads. Therefore, CWCPM has higher activity theoretically.

1.2 Experimental Scheme

The reference mixture ratio of C25 concrete was obtained through orthogonal experiment, as shown in Table 3.

<table>
<thead>
<tr>
<th>Code</th>
<th>W/C</th>
<th>Sand ratio (%)</th>
<th>Consumption of the unit materials (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C25</td>
<td>0.49</td>
<td>33</td>
<td>Cement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>250</td>
</tr>
</tbody>
</table>

Four different CWCPM dosages, i.e., 0%, 20%, 30% and 40%, were selected to study the influence of CWCPM dosage on the mechanical performance and anti-permeability performance of C25 concrete. The curing ages for compressive strength test were 7 d and 28 d, and for flexural strength and anti-permeability performance were 90 days and 28 days, respectively. The method of the anti-permeability performance was rapid chloride ion migration coefficient method (RCM).

2 RESULTS OF MACRO TEST

2.1 Results of Mechanical Performance

The results of compressive strength and flexural strength of the C25 concrete mix with different dosages of CWCPM are shown in Figures 2 and 3.

The above Figures show that the dosage of CWCPM has a certain impact on the mechanical performance of C25 concrete. With the increase of the CWCPM dosage, the 7 d compressive strength of the C25 concrete gradually reduces, whereas the 28 d compressive strength increases initially and then reduces, peaking at CWCPM dosage of 30%. The 90 d flexural strength of the C25 concrete has the same variation with the 28 d compressive strength.
The 7 d, 28 d compressive strengths and the 90 d flexural strength reduce by 14.9%, 3.4% and 14.9% respectively, compared with the reference concrete, when the dosage of CWCPM is 40%. In general, the CWCPM has a positive strength effect, when its dosage is less than 30%, the concrete’s early strength slightly decreases, but the late strength is higher than that of the reference specimen.

2.2 Results of Anti-permeability Performance

The results of anti-permeability performance of C25 concrete mix with different dosages of CWCPM are shown in Figure 4.

Figure 4. Results of anti-permeability test.

Figure 5 shows that the CWCPM improves the permeability resistance of C25 concrete. The chloride ion permeability coefficient decreases first and then increases with the increase of CWCPM dosage. The minimum value is obtained at the dosage of 30%, and the chloride ion permeability coefficient decreases by 44.8% compared with the reference specimen.

The CWCPM improves the anti-permeability performance through the following three aspects. Firstly, the pozzolanic effect of CWCPM improved perfects hydration products, optimizes the boundary structure, increases the compactness and refines the internal pore structures of the C25 concrete, thus reducing the diffusion ability of Cl\(^-\). Secondly, the unhydrated clinker and the low alkalinity C-S-H gel have a physical adsorption of the Cl\(^-\). Thirdly, the Cl\(^-\) can react with hydration aluminate and its derivatives, generating the Friedel salt, thus reducing the content of free Cl\(^-\) inside the concrete\(^{[12]}\).

3 RESULTS OF XRD TESTS

The XRD results of the specimens mixed with 0%, 30% and 40% CWCPM are shown in Figure 5.
Figure 5. XRD test results of different specimens.

Note: Aft-Ettringite; CH-Ca(OH)₂; Si-SiO₂; C-CaCO₃; CS-C₂S; JZ-control specimen; FH30% and FH40%-specimens with 30 wt% and 40 wt% CWCPM respectively.

Figure 5 shows that all the XRD results have the same shape, which indicates that the CWCPM does not generate new hydration products. The typical crystalline substances include Aft, Ca(OH)₂, CaCO₃ and part of unhydrated C₂S and SiO₂. The height of the diffraction peak can qualitatively represent the contents of the materials. By comparing the XRD results of specimens with and without CWCPM, it is clear that incorporating CWCPM significantly reduces the content of Ca(OH)₂. The magnitude of reduction of FH30 % is larger than that of FH40 %, which means that there exists optimal CWCPM dosage, consisting with the macroscopic experimental results. At the same time, the secondary hydration reaction of CWCPM generates low alkalinity C-S-H gel which has a better performance.[13, 14]

The decrease of Ca(OH)₂ content can improve the strength and other performances of the cement base materials. This is because Ca(OH)₂ has a coarse crystalline phase and high orientation, which make it a weak link of the concrete. The low alkalinity C-S-H gel, however, can fill up the pores, reduce the pore porosity and improve the compactness of concrete, thus improving the anti-permeability performance of the concrete.[15, 16]

4 CONCLUSIONS
(1) When replacing part of cement used in C25 concrete, although the concrete’s early strength decreases, CWCPM improves the late strength of the C25 concrete. Its optimal dosage is 30%;
(2) CWCPM reduces the content of Cl⁻ through physical and chemical reactions, therefore improving the anti-penetrability performance of the concrete;
(3) CWCPM perfects the microstructure of the cement-based materials, its pozzolanic reaction reduces the content of Ca(OH)₂ and produces low alkalinity C-S-H gel with a better performance. It also improves the compactness and reduces the pore porosity of the concrete;
(4) CWCPM is a kind of economic and technology feasible new material and it can be used in concrete engineering by replacing part of cement.
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REFERENCES


