INFLUENCE OF STONE DUST IN MANUFACTURED SAND ON RESISTING CHLORIDE PENETRATION IN MARINE CONCRETE

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Abstract

In China, manufactured sand has been widely used as fine aggregate in concrete. Therefore, it is necessary to investigate the effect of manufactured sand on durability of concrete. This research studies the influence of stone dust content in manufactured sand on resisting chloride penetration in marine concrete by strength and other physical mechanical tests, XRD, TGA and pore structure analysis. Test results have shown that the chloride diffusion coefficient increased with increasing the stone dust content in manufactured sand when the stone dust content increasing from 3% to 13%. The stone dust in fine aggregate participated in the hydration of cement, which will promote the hydration degree of the cementitious material and increase the chloride binding capacity of hydration product. The influence of stone dust in fine aggregate on the chloride diffusion coefficient were the combined effects of concrete pore structure and hydration products. The porosity and pore size distribution were the main factors that influence the diffusion coefficient.

1. INTRODUCTION

With the rapid development of infrastructure construction, the natural sand currently used as fine aggregate in concrete does not meet the requirements for engineering construction. Then, the use of manufactured sand to prepare concrete has become a trend. Manufactured sands are produced by crushing rock depositions to produce a fine aggregate, which is generally more angular and has rougher surface texture than natural river sand particles. The production of manufactured sands generates stone dust in the sand production process and the sand production equipment. Then, it is necessary to research the effect of manufactured sand, used as fine aggregate, on the workability of fresh concrete and durability of mature concrete. Many previous studies have shown that good quality concrete can be made using
manufactured sand with high amount of stone dust\cite{1-3}, but studies were focused on the effect of stone dust content on workability of fresh concrete, the compressive and flexural strength for hardened concrete. Up to now, few reports have been devoted to the effect of stone dust content in manufactured sand on resisting chloride penetration in marine concrete. But the chloride diffusion coefficient is an important parameter in view of the durability of concrete. So, in this work, the influence of stone dust on resisting chloride penetration in marine concrete was investigated.

2. EXPERIMENTAL

2.1 Raw materials

The cementitious materials consisted of Graded 42.5R Portland Cement supplied by Yuexiu Cement in Guangdong province, Graded fly ash supplied by Huangpu Power Plant, and slag ground blast furnace slag supplied by Guangzhou Iron & Steel Plant. The chemical compositions of raw materials are given in Table 1. The fine aggregate was manufactured sand and had a fineness modulus of 2.8, made by a wet process from limestone and containing 3.0% stone dust. The density of manufactured sand was 2680 kg/m$^3$. The coarse aggregate was crushed stone with a maximum size of 20 mm, with a density of 2690 kg/m$^3$. High Range Polycarboxylate Water Reducer super-plasticizer, called HSP-V, supplied by Guangzhou Si-hang Material Technology Co Ltd, was incorporated. The XRD pattern of stone dust is shown in Fig.1: The main content of stone dust was limestone.

Table 1: Chemical compositions of raw materials/%

<table>
<thead>
<tr>
<th>Materials</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>Fe$_2$O$_3$</th>
<th>CaO</th>
<th>MgO</th>
<th>SO$_3$</th>
<th>K$_2$O</th>
<th>Na$_2$O</th>
<th>IL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>20.24</td>
<td>4.43</td>
<td>5.30</td>
<td>63.83</td>
<td>0.97</td>
<td>2.85</td>
<td>0.64</td>
<td>0.08</td>
<td>2.68</td>
</tr>
<tr>
<td>Fly ash</td>
<td>60.81</td>
<td>24.12</td>
<td>5.76</td>
<td>3.03</td>
<td>0.55</td>
<td>1.31</td>
<td>0.71</td>
<td>0.32</td>
<td>3.26</td>
</tr>
<tr>
<td>Slag</td>
<td>34.20</td>
<td>13.39</td>
<td>1.20</td>
<td>38.20</td>
<td>9.02</td>
<td>0.28</td>
<td>0.20</td>
<td>0.51</td>
<td>2.73</td>
</tr>
</tbody>
</table>

Fig.1 XRD pattern of stone dust
2.2 Mix proportion and specimen preparation

Usually, in concrete for marine environments, relatively richer mixes with low water to cementitious material ratio are used. Based on previous experimental results, the cementitious materials in this study was 480 kg/m\(^3\) at a W/C of 0.32, and the cement was replaced by fly ash and slag at 20% and 30%, respectively. The slump for fresh concrete was no less than 160 mm by adding different content of super-plasticizer.

Furthermore, the composite cementitious pastes were prepared at the W/C ratio of 0.32, stone dust were used at levels of 3%, 5%, 7% and 10%, respectively, and the inert quartz powder was used at a level of 10%, which is used to test the chloride binding capacity of hardened pastes at 28 days. The stone dust and the inert quartz powder have the same fineness. The mix proportion and the compressive strength are listed in Table 2.

Table 2: Mix proportion and compressive strength of concretes at 28 and 56 days

<table>
<thead>
<tr>
<th>Type</th>
<th>Mix proportion (kg/m(^3))</th>
<th>SP (%)</th>
<th>Compressive strength (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Binder</td>
<td>Fine aggregate</td>
<td>Stone dust</td>
</tr>
<tr>
<td>L3</td>
<td>480</td>
<td>712</td>
<td>0</td>
</tr>
<tr>
<td>L5</td>
<td>480</td>
<td>697</td>
<td>15</td>
</tr>
<tr>
<td>L7</td>
<td>480</td>
<td>683</td>
<td>29</td>
</tr>
<tr>
<td>L10</td>
<td>480</td>
<td>660</td>
<td>52</td>
</tr>
<tr>
<td>L13</td>
<td>480</td>
<td>639</td>
<td>73</td>
</tr>
</tbody>
</table>

It can be seen from Table 2 that the compressive strength of specimens at different ages increased with increasing the stone dust content in the ranges of 3%~13%.

2.3 Testing Methods

The chloride diffusion coefficient (\(D_s\)) was determined by the Nordtest method NT BUILD 443\(^4\). The chloride binding capacity of hardened pastes was determined by Tang’s methods\(^5\). The chloride concentration was tested by means of an automatic potentiometric titrator supplied by Metrohm. The X-ray diffraction analyses were performed on a D/max-III A system supplied by Rigaku Corporation. The Ca(OH)\(_2\) content in hardened pastes was determined using a Thermogravimetric Analyzer (TGA) supplied by Perkin-Elmer Corporation, the furnace temperature was raised from ambient temperature to 600°C at a constant rate. The total porosity of concrete was determined using a mercury intrusion porosimeter (MIP) supplied by ThermoFinnigan Corporation (Pascal 140 and Pascal 240).

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Influence of stone dust content on chloride diffusion coefficient

The influence of the stone dust content in manufactured sand on chloride diffusion coefficient in concrete specimens was shown in Fig.2.
Fig. 2 Influence of stone dust content on chloride diffusion coefficient of concrete

It can be seen from Fig. 2 that the chloride diffusion coefficient in concrete specimens increased with increasing stone dust content in manufactured sand at 28 days and 56 days, and the chloride diffusion coefficient for specimens cured for 56 days were lower that cured for 28 days. The chloride diffusion coefficient increased rapidly when the stone dust content increased from 3% to 7%, but the chloride diffusion coefficient increased little when the stone dust content increased from 7% to 13%.

3.2 Influence of stone dust content on chloride binding capacity of hardened pastes

The influence of stone dust content on total binding of chloride of hardened pastes at a concrete age of 28 days and 56 days is shown in Fig. 3. The bound chloride of hardened pastes decreased with increasing stone dust content in composite cements at 28 days and 56 days, and the bound chloride of pastes at 56 days was higher than that at 28 days. According to Tang’s results, the bound chloride of concrete strongly depends on the content of CSH gel in the concrete, then it can be seen that the content of CSH gel in hardened pastes decreased with increasing the stone dust content in composite cementitious, which led to lower amount of bound chloride in the paste.

In this work, when increasing the stone dust content in fine aggregate, the cementitious proportion in composite cementitious decreased when increasing the stone dust content. Fig. 4 showed the influence of stone dust content on chloride binding capacity of hydration product at 28 days.
Fig. 3 Influence of stone dust content on binding chloride of hardened pastes

![Graph showing influence of stone dust content on binding chloride of hardened pastes](image)

Fig. 4 Influence of stone dust content on binding capacity of hydration product at 28 days

It can be seen from Fig. 4 that the chloride binding capacity of the hydration product increased slightly with increasing stone dust content in composite cementitious material, and increase hydration product. The reason may be due to the limestone reacts with C₃A and C₃S to form calcium aluminate carbonates, CSH and Ca(OH)₂ [6-7].

3.3 Influence of stone dust content on hydration of composite cementitious

Fig. 5 shows TGA plots for different hardened paste at 28 days. For the regions from about 450°C ~ 500°C, there was an abrupt weight loss which is associated with the decomposion of Ca(OH)₂ [8-9]. The abrupt weight loss decreased when the composite cement is replaced by stone dust and quartz powder.
Compared the stone dust sample with the quartz sample, the Ca(OH)$_2$ content in the stone dust sample was higher than in the quartz sample, so, the hydration degree of composite cementitious in stone dust sample was higher than that in quartz sample.

Then it can be learned from above results that the stone dust will participate in hydration of cement, which will promote the hydration degree of cementitious.

### 3.4 Influence of stone dust content on concrete pore structure

The concrete pore structure includes the porosity, average pore size, pore size distribution and so on\(^{[10]}\). Ordinarily the more the ratio of gel pore and transitional pore, the better the durability of concrete are. The influence of stone dust content on concrete pore structure was listed in Table 3.

**Table 3: Influence of stone dust content on concrete pore structure**

<table>
<thead>
<tr>
<th>Type</th>
<th>Porosity (%)</th>
<th>Average pore size (nm)</th>
<th>Pore size distribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>&lt;10nm</td>
</tr>
<tr>
<td>L03</td>
<td>10.58</td>
<td>19.49</td>
<td>15.97</td>
</tr>
<tr>
<td>L05</td>
<td>11.42</td>
<td>20.54</td>
<td>15.54</td>
</tr>
<tr>
<td>L07</td>
<td>13.14</td>
<td>21.15</td>
<td>16.32</td>
</tr>
<tr>
<td>L10</td>
<td>14.09</td>
<td>23.47</td>
<td>15.37</td>
</tr>
<tr>
<td>L13</td>
<td>14.92</td>
<td>25.12</td>
<td>15.19</td>
</tr>
</tbody>
</table>

Table 3 shows that the porosity and the average pore size of concrete increased with increasing stone dust content in fine aggregate, the proportion of gel pore and transitional pore increased little when the stone dust content in fine aggregate increasing from 3% to 13%. The proportion of transitional pores and capillary pores decreased and increased with increasing the stone dust content, respectively.

In general, the chloride binding capacity of hydration products and the concrete pore...
structure were the two main factors that influence the changes of chloride diffusion coefficient in hardened concrete. In this work, the hydration degree of cementitious powder increased slightly with increasing the stone dust in fine aggregate, which led to an increase of the chloride binding capacity, but meanwhile, it led to increase the porosity and average pore size in concrete. Then, it can be concluded that the porosity and pore size distribution were the main factors that influence the changes of diffusion coefficient, and the diffusion coefficient decreased with decreasing the porosity, the proportion of capillary pore and macro pore.

4. CONCLUSIONS

- The chloride diffusion coefficient in concrete increased with increasing the stone dust content in manufactured sand at 28 days and 56 days when the stone dust content increasing from 3% to 13%.
- The stone dust in fine aggregate participated in the hydration process of cementitious powders which will promote the hydration degree of cement and increase the chloride binding capacity of hydration product.
- The influence of stone dust in fine aggregate on the chloride diffusion coefficient is the result of the combined effects of changes of the concrete pore structure and the hydration products. The chloride diffusion coefficient decreased with decreasing porosity and decreasing the proportion of capillary pore and macro pore. The porosity and pore size distribution were the main factors that influence the changes of diffusion coefficient.

References
