Mechanical Property of Concrete Pavement Composed of Machine-made Sand Concrete and Natural Sand Concrete Layers

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Abstract. Adopting the composed cement concrete pavement of machine-made sand concrete and natural sand concrete not only can reduce to dig the natural river sand and protect the environment, but also can ensure the functional requirements of the cement concrete surface layer. This paper studies the differences of work performances and mechanical properties through contrasting machine-made sand concrete and natural sand concrete, then it carries on mechanical properties tests of the composed concrete samples towards the lower layer 100 mm of machine-made sand concrete and the upper level layer 50 mm of natural sand concrete. Besides it also explores a perfect paving opportunity of the upper natural sand concrete.

Introduction

Machine-made sand is a rock through falling into pieces and screening, which is a granule that the grain size is less than 4.75 mm. The resources of machine-made sand distribute extensively, which is free from the conditional limit of geography and can be exploited nearby to save the freight greatly. Since the exploration expenses of machine-made sand is barely 1/3 of natural sand concrete, it is subject to be loved among more and more road workers. Machine-made sand recently is widely used between the construction industry and the traffic construction industry, while it is mainly used in bridges and piles foundation engineering in the traffic construction industry. Due to its higher abrasion and poorer abrasion-resistance, machine-made sand is rarely used in the cement pavement. The cement concrete pavement has a higher requirement for abrasion, the abrasion of machine-made sand concrete can not reach the cement concrete pavement related specification requirements. The cement concrete pavement mainly uses natural sand as fine aggregate. White and white integral cement pavement is a machine-made sand concrete coupled with natural sand concrete integral pavement that incorporate the bargain price, abundant resources of machine-made sand and the well-graded, abrasion of natural sand, which not only meets the abrasion requirements of cement concrete pavement but also reduces project cost.

This text is based on researches the differences of work performances and mechanical properties through contrasting machine-made sand concrete and natural sand concrete, which carries on mechanical properties tests of the composite concrete that is consisted of machine-made sand concrete and natural sand concrete. Meanwhile, the text explores a perfect paving opportunity of the upper natural sand concrete.

Experimental Meaterials

Raw Materials
1). Cement: P.O 42.5 ordinary Portland cement, the cement physical indicators are shown in the table I.
Table I. Cement physical indicators.

<table>
<thead>
<tr>
<th>Fineness</th>
<th>Initial Setting Time</th>
<th>Anti-fracture Strength (MPa)</th>
<th>Compressive Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve residue 80um square hole sieve (%)</td>
<td>Initial setting</td>
<td>Final setting</td>
<td>3D</td>
</tr>
<tr>
<td>2.8</td>
<td>237</td>
<td>306</td>
<td>4.9</td>
</tr>
</tbody>
</table>

2). The performance indicators of coarse aggregate, machine-made sand and natural sand are shown in the table II.

Table II. Performance indicators of coarse aggregate machine-made sand and natural sand.

<table>
<thead>
<tr>
<th>Coarse Aggregate (limestone)</th>
<th>Natural Sand</th>
<th>Machine-made Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent density (g/cm³)</td>
<td>Apparent density (g/cm³)</td>
<td>Apparent density (g/cm³)</td>
</tr>
<tr>
<td>Max particle-size (mm)</td>
<td>Fineness modulus (%)</td>
<td>Fineness modulus (%)</td>
</tr>
<tr>
<td>2.715</td>
<td>31.5</td>
<td>2.664</td>
</tr>
<tr>
<td>2.664</td>
<td>2.71</td>
<td>2.705</td>
</tr>
<tr>
<td>2.715</td>
<td>10.7</td>
<td>2.79</td>
</tr>
</tbody>
</table>

The Mix Proportion of Concrete

The Mix Proportion of Machine-Made Concrete. The mix proportion of machine-made sand concrete is designed according to 5.0 design label and its stone content is twenty percent of fine stone, eighty percent of coarse stone, thirty-seven percent of sand ratio. Meanwhile the cement is ordinary Portland cement (P.O42.5), the design slump of concrete is 30mm-60mm and its design unit weight is 2400kg/m³. The result is shown in the table III.

Table III. Mix proportion of machine-made sand concrete.

<table>
<thead>
<tr>
<th>Sand Ratio (%)</th>
<th>Design Mixture Ratio</th>
<th>Consumption of per cubic meter of concrete material</th>
</tr>
</thead>
<tbody>
<tr>
<td>c: s: g: w</td>
<td>Cement</td>
<td>Machine-made sand</td>
</tr>
<tr>
<td>37</td>
<td>1:2.0:3.41:0.43</td>
<td>351</td>
</tr>
</tbody>
</table>

The Mix Proportion of Natural Sand Concrete. The mix proportion of natural concrete is designed according to 5.0 design label and its stone content is twenty percent of fine stone, eighty percent of coarse stone, thirty-six percent of sand ratio. Meanwhile the cement is ordinary portland cement (P.O42.5), the design slump of concrete is 30mm-60mm and its design unit weight is 2450kg/m³. The result is shown in the table IV.
Table IV. Mix proportion of natural sand concrete.

<table>
<thead>
<tr>
<th>Sand Ratio (%)</th>
<th>Design Mixture Ratio</th>
<th>Consumption of per cubic meter of concrete material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>c: s: g: w</td>
<td>Cement</td>
</tr>
<tr>
<td>36</td>
<td>1:1.90:3.37:0.4</td>
<td>360</td>
</tr>
</tbody>
</table>

Performance Comparison between Machine-Made Sand Concrete and Natural Sand Concrete

In order to study performance difference between machine-made sand concrete and natural sand concrete, under the condition of their optimum mixture ratio, we research the differences of work performances and mechanical properties through constrasting machine-made sand concrete and natural sand concrete.

Work Performance

Fresh concrete is a kind of plastic material, it need be transported, poured and vibrated when constructing. Workability mainly describes a kind of ability that transports fresh concrete and vibrates compaction. We describe this concrete that it can easily be transported, poured, dressed, plastered and it can not generate bleeding isolation as better workability, otherwise as poor workability. Workability is a synthetic indicator that it includes three meanings of liquidity, cohesiveness, water retention.

Liquidity. Fresh concrete material is a kind of solid, liquid mixing dispersion system and it has deformational properties because it overcomes the inner resistance from dispersion system. The size of liquidity depends on the proportion of solid phase, liquid phase. When liquid phase increases, it expands the average spacing of solid dispersion system, that is, it enhance liquid. When constructing, the flowing property of external concrete performance is a ability that it can flow and uniform densely to fill in the template under its own gravity or mechanical vibrating effect. The stand or fall of liquidity is closely related to the construction technology and the usefulness of concrete. If liquidity is too large, the concrete mixture is too lean that it appears easily laitance leading to the layer and education for concrete and influencing the uniform and the compactness after concrete hardening. If liquidity is too little, the concrete is too thick that vibrating compaction need lots of energy. So it could not be vibrated compaction that leads to appear flaw such as cavity of the concrete interior or surface after hardening.

Cohesiveness. Cohesiveness is know as rheology’s plasticity that overcomes the yield strength from this decentralized system of concrete mixture producing the irreversible distortion. It has nothing to do with the proportion of solid, liquid phase and it depends on molecular attraction from unit of distance between the particle in disperse phase. The molecular attraction of adhesiveness ensures concrete will not occur the layer and education and makes concrete maintain integrity, stability. The poor cohesiveness of concrete easily happens a phenomenon of segregation between slurry and aggregate during construction, which leads to make slurry distribute unevenly. A place lack of slurry easily generates honey combs and cavity. But too much cohesion of concrete liquidity becomes poor, so judging cohesiveness whether it is appropriate according to the specific requests of construction.

Water Retention. Water retention reflects a ability to maintain the uniform distribution in the body of aggregate under the external force, that is just because of the aggregate sinking leading to a separate phenomenon of solid, liquid phase. The better water retention of concrete do not appear a phenomenon of bleeding isolation seriously during construction. While a part of water precipitates
out from the inside to the surface in the poor water retention of concrete and leaves many capillaries with water loss that greatly decreases the impermeability of concrete matrix.

The experiment result of work performance from machine-made sand concrete and natural sand concrete is shown in the table V.

Table V. Work performance of machine-made sand concrete and natural sand concrete.

<table>
<thead>
<tr>
<th>Type Of concrete</th>
<th>Slump (mm)</th>
<th>Adhesiveness</th>
<th>Water Retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine-made sand concrete</td>
<td>55</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>Natural sand concrete</td>
<td>45</td>
<td>better</td>
<td>Slight bleeding</td>
</tr>
</tbody>
</table>

The work performance of natural sand concrete is better than machine-made sand concrete’s according to the table V and the slump of natural sand concrete is 5mm higher than machine-made sand concrete’s, which illustrate the liquidity of natural sand concrete is better than machine-made sand concrete’s. The main reason is that rough surface and angular of machine-made sand increase the friction among aggregate. While due to the washed water, the surface of natural sand becomes smooth to decrease the friction between sand and aggregate. Meanwhile machine-made sand contains tiny amounts of stone powder increasing water requirement of concrete to make concrete become thickness. The adhesiveness of natural sand concrete is better than machine-made sand concrete’s, because the graduation of natural sand is superior to machine-made sand concrete’s. Machine-made sand gets through mechanical crushing, screening and its graduation distributes poorly, meanwhile it can easily take away a part of fine aggregate during wet dust removal. The water retention of natural sand concrete is good while machine-made sand concrete appears slight bleeding. The power of machine-made sand concrete is a main reason that influences its water retention, therefore, it should strictly control the content of stone powder. In a word, the work performance of natural sand concrete is superior to machine-made sand concrete’s.

**Mechanical Property**

The rupture strength of concrete is a indicator that judges the quality of concrete. Meanwhile there are many factors influencing the rupture strength of concrete, the quality of sand has a more significant impact on its rupture strength. In order to study machine-made sand and natural sand how to influence the rupture strength of concrete, this section makes up two kinds of concrete according to the mixture ratio of the table III and table IV.

It determines the rupture strength of seven day and twenty-eight day in the standard curing room. The experimental result of rupture strength from machine-made sand concrete and natural sand concrete is shown in the figure I.

Table VI. The rupture strength of machine-made sand concrete and natural sand concrete.

<table>
<thead>
<tr>
<th>Type of concrete</th>
<th>rupture strength of seven day</th>
<th>rupture strength of twenty-eight day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural sand concrete</td>
<td>5.7</td>
<td>6.8</td>
</tr>
<tr>
<td>Machine-made sand concrete</td>
<td>5.4</td>
<td>6.0</td>
</tr>
</tbody>
</table>
The seven-day and twenty-eight-day of rupture strength for natural sand concrete are larger than machine-made sand concrete’s, meanwhile the growth rate of strength from natural sand concrete is quicker than machine-made sand concrete’s. This main reason is that the graduation of machine-made sand is poorer. Producing the graduation of machine-made sand distributes worse after the rock sieves brokenly, the internal of poor graduation from machine-made sand concrete has plenty of interstice, meanwhile it easily forms the weak interface between cement and machine-made sand that goes against forming concrete. The particle shape of concrete is irregular, crushing value is larger and the more flat-elongated particles decrease the rupture strength of concrete. The stone powder of machine-made sand is another important factor that influences the rupture strength of concrete. The appropriate stone powder can fill in the internal interstice of concrete and promote the cement hydraulic reaction, while the content of stone powder has a certain damage to the strength of concrete. Therefore it should strictly control the stone powder of machine-made sand. Instead due to the scouring effect of river, particle uniformly distributes and it presents cubic or roundness. The crushing value of natural sand is lower and natural sand is very hard. Meanwhile the graduation of natural sand is better and impurity such as the content of stone powder is less. All of these factors are conducive to form the rupture strength of concrete. Therefore, the rupture strength of natural sand concrete is superior to machine-made sand concrete’s.

**Study the Paving Time of the Upper Layer from Natural Sand Concrete**

The lower machine-made sand concrete couple with the upper natural sand concrete form the composite pavement, while the key of quality is the paving time of the upper layer from natural sand concrete. The early paving time of the upper layer goes against construction organization and it brings trouble to construction. The paving time of the lower machine-made sand concrete is too late and the hydration degree of lower machine-made sand concrete tend to be complete, which will influence the interfacial bond of concrete, thereby it has an effect on the integrity of concrete pavement.

In order to determine the best paving time of the upper layer from natural sand concrete, we study the paving time of the upper layer from natural sand concrete. The composite pavement adopts the lower 100mm machine-made sand concrete couple with the upper 50mm natural sand concrete. Firstly it shapes the lower 100mm machine-made sand concrete, secondly the interval for overlaying the upper natural sand concrete is regarded as a variable, the intervals are 30min, 60min, 90min, 120min, 150min, 180min, 210min, 240min.

The specimens are maintained seven day under the condition of standard curing and the results are shown in the figure II.
Table VII. The standing time of the lower machine-made sand concrete has an effect on compression strength of monolithic concrete.

<table>
<thead>
<tr>
<th>Standing time of the lower machine-made sand (min)</th>
<th>Compression strength of seven day (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>37.1</td>
</tr>
<tr>
<td>60</td>
<td>36.8</td>
</tr>
<tr>
<td>90</td>
<td>35.1</td>
</tr>
<tr>
<td>120</td>
<td>34.4</td>
</tr>
<tr>
<td>150</td>
<td>33.6</td>
</tr>
<tr>
<td>180</td>
<td>33.3</td>
</tr>
<tr>
<td>210</td>
<td>34.2</td>
</tr>
<tr>
<td>240</td>
<td>34.9</td>
</tr>
</tbody>
</table>

According to the picture 2, the compressive strength of monolithic concrete tend to increase at first and then decrease with the increasing standing time of the lower machine-made sand concrete. The compressive strength of “white and white” monolithic concrete is 37.1MPa after the standing time is 30 min. The compressive strength of “white and white” monolithic concrete gradually decreases as the lower standing time increases.

The compressive strength reaches the minimum 33.3MPa, then the compressive strength tends to increase when the standing time gets to 180min.

The specimens that the different interval for overlaying the upper natural sand concrete go through compressive test, then the results are shown in the figure 3. Seen from the appearance of specimen, the boundary of two layers concrete is gradually clear with the increasing standing time of the lower machine-made sand concrete.

When the standing time of the lower machine-made sand concrete is 30min~90min, the specimen barely distinguishes the boundary of two layers concrete. Meanwhile the specimen presents integral destruction and the cracks get through the integral specimen after compression test. When the standing time of the lower machine-made sand concrete is 120min~240min, the surface of specimen gradually presents chromatic aberration. The color of two layers concrete is gradually clear with the increasing standing time of the lower machine-made sand concrete. Especially after the standing time of the lower machine-made sand concrete exceeds 180min, the chromatic aberration is quite obvious, the thinner and black of the upper is natural sand concrete and the thicker and white of the lower is machine-made sand concrete. After specimen gets through compression test, the main parts of destruction is the lower of specimen, meanwhile the upper natural sand concrete hardly appears flaws, it is more obvious with the increasing standing time of the lower machine-made sand concrete.

The initial setting time of experimental concrete is 237min. When standing time of the lower machine-made sand concrete is less than 120min, the lower machine-made sand concrete just begins. With standing time increasing, the degree of cement hydration reaction is gradually deepened. When standing time of the lower machine-made sand concrete is less than 180min, with the increasing time, the closely degree of interface combination decreases between the upper natural sand concrete and the lower concrete and the integration for two layers concrete decreases. So
Compressive strength gradually decreases with the increasing standing time of lower concrete, the boundary of two layers becomes clear. When standing time of the lower machine-made sand concrete is more than 180min, the cement hydration reaction is gradually finished. The surface of lower machine-made sand concrete becomes hard and the upper machine-made sand concrete is difficult to permeate into the lower. The interface combination of two layers is very low. Therefore the lower thicker of machine-made sand concrete plays a leading role during compression test. In order to reach a balance between the strength of “white and white” monolithic concrete and convenient construction, this upper natural sand concrete should be finished before the initial setting of the lower machine-made sand concrete and the standing time of lower machine-made sand concrete should be controlled within 90min.

Figure III. Compression state of specimen from different standing time of machine-made sand concrete.

Conclusion
The work performances and mechanical properties of natural sand concrete is superior to machine-made sand concrete’s.

With the increasing standing time of the lower machine-made sand concrete, compassion strength of “white and white” monolithic concrete pavement tends to decrease at first and then increase. The standing time of lower machine-made sand concrete should be controlled within 90min.

References


