Experimental study on the effect of stone powder content on the plastic shrinkage of self-compacting concrete at early age

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Abstract. To investigate the effect of water-cement ratio and stone powder admixture on the plastic shrinkage performance of self-consolidated concrete by measuring the shrinkage deformation within 24 hours after casting through non-contact shrinkage test. The test shows that the larger the water-cement ratio and the higher the stone powder admixture, the larger the early-age shrinkage value; the early-age shrinkage growth rate is mainly affected by the water-cement ratio, and the early-age shrinkage growth rate tends to level off later for small water-cement ratio; the effect of stone powder admixture on different water-cement ratios is slightly different, and the increase effect of stone powder admixture on early-age shrinkage is more obvious under the high water-cement ratio condition.

1. Introduction

Early-age shrinkage refers to the volume deformation caused by non-loading factors such as chemical reaction, aggregate settlement and water evaporation before the concrete is completely hardened after pouring. The factors that affect the early-age shrinkage mainly include internal mix components and external curing environment. In the early age stage, the concrete strength is not fully developed, and the shrinkage deformation is too large, which makes the local stress greater than the current concrete strength, causing macro cracks and even intermittent cracks\textsuperscript{[1]}.

Wang Haiyang\textsuperscript{[2]} and Yang Kai\textsuperscript{[3]} studied the water-binder ratio, mineral content, temperature, humidity and wind speed from two aspects of raw materials and curing environment to measure the plastic shrinkage of ordinary concrete within 5 hours after pouring. The study showed that as the water-binder ratio increases, the plastic shrinkage increases. The incorporation of silica fume will increase the amount of plastic shrinkage. There are differences in the evaporation of water on the surface of the concrete under different humidity and wind speeds, which will affect the plastic shrinkage. Xie Tao\textsuperscript{[4]} measured the effect of the amount of water reducing agent on the plastic shrinkage under the conditions of three mix ratios. The results show that within the threshold, the influence of the water-reducing agent content is not significant. When the water-reducing agent exceeds the threshold, the water-reducing agent has a significant impact on the plastic shrinkage, and the threshold is determined by the mixing ratio conditions. Feng Hao\textsuperscript{[5]} studied different powders through plastic shrinkage The plastic shrinkage development law of high performance concrete under the conditions of coal ash content, silica fume content and water-binder ratio. Research shows that within a certain range, the mixing of fly ash and silica fume can reduce the plastic shrinkage, and the plastic shrinkage increases with the water-binder.
The shrinkage characteristics of machine-made sand self-compacting concrete mainly study auto-shrinkage and drying shrinkage\cite{6}, and there is a lack of research on early age shrinkage. Machine-made sand self-compacting concrete has the characteristics of low water-binder ratio and multi-stone powder content. The mechanism of stone powder on concrete shrinkage is more complicated, and the early-age shrinkage law is obviously different from that of ordinary concrete\cite{7}. In this paper, the water-binder ratio and stone powder content are used as variables, and the non-contact shrinkage test method is used to study the effect of water-binder ratio and stone powder content on machine-made sand. The influence of compacted concrete’s early age shrinkage performance.

2. Materials and Methods

2.1. Concrete raw materials

The cement used in this test is the Beijing JinYu brand P.O 42.5 cement, the fly ash is grade II fly ash, and the coarse aggregate is a two-stage aggregate with a particle size of 5-10mm and 10-20mm. 10-20mm aggregate accounts for 60% of the total aggregate. Quartz sand includes 0.125-0.180mm, 0.180-0.425mm, 0.425-0.850mm, 0.850-2.00mm, 2.00-4.75mm in five particle sizes. For the gradation of particles, the different particle sizes of quartz sand are prepared according to the ratio shown in Table 1. The amount of stone powder in the quartz sand is adjusted by adding stone powder. After the preparation, the sand gradation curve is located in zone II. The acid water reducer is prepared by the mother liquor of water reducer and plasticizer produced by Beijing Hua Shi Na Gu Technology Co., Ltd. at a ratio of 1:1. The density of the main materials is shown in Table 2.

| Size/mm | 0.125-0.180 | 0.180-0.425 | 0.425-0.850 | 0.850-2.00 | 2.00-4.75 |
|---------|-------------|-------------|-------------|------------|------------|
| Proportion | 21%         | 21%         | 23%         | 20%        | 15%        |

Table 2. Density of main material

| Material | Cement | Fly ash | Aggregate | Quartz sand | Powder |
|----------|--------|---------|-----------|-------------|--------|
| Density (g/mm$^3$) | 3.09 | 2.21 | 2.79 | 2.78 | 2.79 |

2.2. Mixture design

The shrinkage test refers to the requirements for shrinkage test in the "Test Methods for Long-term Performance and Durability of Ordinary Concrete" (GB/T50082-2009), and is carried out using the CABR-NES non-contact concrete shrinkage deformation tester developed by the China Academy of Building Research Measure the shrinkage deformation of machine-made sand self-compacting concrete within 24 hours after pouring. Considering the influence of water-binder ratio and stone powder content on the early-age shrinkage of machine-made sand, after many trials, the mix ratio of machine-made sand self-compacting concrete is determined, as shown in the table 3 shown.

| Number | w/b | Powder | Cement | Fly ash | Quartz sand | Aggregate | Water | Superplasticizer |
|--------|-----|--------|--------|---------|-------------|-----------|-------|-----------------|
| 0.9-00 | 0.9 | 0%     | 486.6  | 87      | 850.68      | 837       | 173.96| 4.0             |
| 0.9-10 | 20% | 10%    | 486.6  | 87      | 850.68      | 837       | 173.96| 4.0             |
| 0.9-20 | 0%  | 20%    | 486.6  | 87      | 850.68      | 837       | 173.96| 4.0             |
| 1.0-00 | 0%  | 10%    | 462.26 | 82.65   | 850.68      | 837       | 183.95| 3.8             |
| 1.0-10 | 1.0 | 0%     | 462.26 | 82.65   | 850.68      | 837       | 183.95| 3.8             |
| 1.0-20 | 20% | 0%     | 462.26 | 82.65   | 850.68      | 837       | 183.95| 3.8             |
| 1.1-00 | 0%  | 10%    | 440.24 | 78.72   | 850.68      | 837       | 193.2 | 3.6             |
| 1.1-10 | 1.1 | 0%     | 440.24 | 78.72   | 850.68      | 837       | 193.2 | 3.6             |
| 1.1-20 | 20% | 0%     | 440.24 | 78.72   | 850.68      | 837       | 193.2 | 3.6             |
3. Results & Discussion

3.1. The effect of water-binder ratio on the shrinkage of MS-SCC at early age

The change curve of early-age shrinkage rate under different water-to-rubber ratio conditions is shown in Figure 1.

![Figure 1. Influence of different water-binder ratio on shrinkage at early age](image)

(a) Stone powder content 0%
(b) Stone powder content 10%
(c) Stone powder content 20%

It can be seen from Figure 1 that in the first 4 hours, the change slope of the shrinkage rate with a low water glue ratio is slightly larger, indicating that the water glue ratio is lower in the initial hydration reaction more intensely, the hydration heat temperature rises quickly, and the shrinkage change rate and total shrinkage are both Slightly larger than the water-to-cement ratio; the shrinkage curve gradually tends to be flat around 8-12h, the water-to-binder ratio has little effect on the time for the shrinkage to enter the stable stage, and has a greater effect on the total shrinkage. When the amount of stone powder is the same, the lower the water-to-cement ratio, the greater the total shrinkage of concrete will be.

When the stone powder content is 0%, the corresponding 24h shrinkage under the conditions of 0.9, 1.0 and 1.1 for water-to-binder ratio are 800.75, 732.13 and 563.01. Compared with the water-to-binder ratio of 1.1, the 24h shrinkage for the water-to-binder ratio of 1.0 and 0.9 The total amount is increased by 30% and 42% respectively; when the stone powder content is 10%, the corresponding 24h shrinkage under the conditions of 0.9, 1.0 and 1.1 in the water-to-binder ratio is 950.16, 805.29 and 700.23, compared to the water-to-binder ratio of 1.1 When the water-binder ratio is 1.0 and 0.9, the total 72h shrinkage is increased by 15% and 36%, respectively; when the stone powder content is 20%, the 24h shrinkage under the conditions of water-binder ratio 0.9, 1.0 and 1.1 is 1059.89, 910.25 Compared with 856.79, when the water-to-cement ratio is 1.1, the total 24h shrinkage of the water-to-cement ratio 1.0 and 0.9 increases by 6% and 24%, respectively. It shows that the plastic shrinkage increases with the decrease of the water-to-cement ratio at the same amount of stone powder. The increase in the amount...
of cement will increase the total heat of hydration of unilateral concrete, resulting in an increase in the total amount of shrinkage in 24 hours. The effect of water-binder ratio on plastic shrinkage varies with the amount of powdered stone. Under the condition of low powdered stone content, plastic shrinkage will be more sensitive to changes. Under the condition of low stone powder content, the cement material is in contact with water more fully, and the amount of cement with low water-to-binder ratio is larger, the water demand and heat release during the hydration process are more, and the internal humidity is reduced. Obviously, thereby increasing the plastic shrinkage rate.

3.2. The effect of stone powder content on the contraction of MS-SCC at early age

The shrinkage curve of MS-SCC with different water-to-glue ratios is shown in Figure 2.

![Shrinkage curve of MS-SCC with different water-to-binder ratios](image)

Figure 2. Influence of different stone powder content on shrinkage at early age

It can be seen from Figure 2 that in the first 4 hours, there is no significant difference in the shrinkage rate under different stone powder content, indicating that the stone powder content has little effect on the early shrinkage under different water-to-binder ratios; about 8 hours, the shrinkage curve gradually tends to gentle, under the same conditions of water-to-binder ratio, the larger the amount of powdered stone will result in greater shrinkage. The large amount of powdered stone will decrease the relative humidity inside the concrete, which will have a negative effect on the volume stability of the concrete.

When the water-binder ratio is 0.9, the 24h shrinkage of 0%, 10%, and 20% of the stone powder content are 800.75, 950.16, and 1059.89, respectively. Compared with the stone powder content of 0%, the stone powder content is 10% and 20%. The total 24h shrinkage increases by 19% and 32%, respectively; when the water-binder ratio is 1.0, the 24h shrinkage of 0%, 10%, and 20% of the stone powder content are 732.13, 805.29 and 912.25, respectively, compared with the stone powder content of 0%, the 24h shrinkage of 10% and 20% stone powder will increase by 10% and 25% respectively; when the water-binder ratio is 1.1, the shrinkage of 0%, 10% and 20% of stone powder will be 563.01,
respectively. , 700.23 and 856.79, compared with the stone powder content of 0%, the stone powder content of 10% and 20% of the 24h shrinkage increased by 24% and 52%, respectively. It shows that the stone powder content increases under the same water-binder ratio. It will increase the total water demand of the powder, reduce the free water and make the interior tend to be dry, and the mixing of a large amount of stone powder will change the compactness of the concrete. Too much stone powder will increase the void volume and uneven distribution of voids. Has an adverse effect on the shrinkage of concrete. The influence of stone powder content on plastic shrinkage is slightly different due to different water-to-binder ratios. Under high water-binder ratio conditions, plastic shrinkage is more sensitive to changes in stone powder content, and stone powder is regarded as gelling Material composition. The amount of cement is relatively small in the condition of high water-to-binder ratio. The increase in the amount of cementitious material caused by the addition of the same amount of stone powder is greater, which makes the plastic shrinkage change more obvious.

4. Conclusion
In this paper, the early age shrinkage performance test of machine-made sand self-compacting concrete considering the content of stone powder is carried out, and the laws of water-binder ratio, stone powder content and its early age shrinkage are explored. The main conclusions are as follows:

1) Cement is the main factor that causes shrinkage in the process of concrete hydration. In the case of the same amount of stone powder, every time the water-binder ratio decreases by 0.1, the shrinkage at the early age increases by 10%. Therefore, for machine-made sand with low water-binder ratio The shrinkage of self-compacting concrete at an early age requires sufficient attention.

2) The lower the water-to-binder ratio, that is, the smaller the relative water consumption, the more intense the internal hydration reaction of the concrete, and the greater the average shrinkage rate. The heat caused by the hydration reaction is released to the outside, making the gelling particles Shrinkage stress is generated between them. In practical applications, the effects of cement and water should be considered comprehensively, and the relative water consumption should be controlled to improve the shrinkage performance of self-compacting concrete.

3) The influence of stone powder content on the shrinkage performance of machine-made sand self-compacting concrete cannot be ignored. Under the same water-binder ratio, when the stone powder content is in the range of 20%, every 10% increase in stone powder content will shrink at an early age. Will increase by 20%.

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