Experimental Study on Early Drying Shrinkage of Self-compacting Barite Concrete

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Abstract. In this paper, raw materials such as fly ash-S95 grade mineral powder composite mineral admixture, barite coarse and fine aggregate and polycarboxylic acid water reducer are selected to successfully formulate C30 self-compacting barite concrete with good performance. It also analyzes the development law of early drying shrinkage of self-compacting barite concrete with age, and discusses the effects of fly ash and slag mixing ratio and water reducer content on concrete work, compressive strength and early drying shrinkage. The results show that: the drying shrinkage of self-compacting barite concrete develops rapidly within 1 day of age, and the drying shrinkage rate at 1 day accounts for 50% to 66% of that at 7 days of age, and then the growth trend is slow; as the proportion of fly ash increases, the performance of the concrete mixture improves. While the strength of concrete decreases in the early and mid-term, the strength gradually increases in the later period, and the shrinkage strain of concrete in the early stage also increases significantly; the proper amount of water-reducing agent can greatly improve the fluidity of the mixture. In the dosage range of 1.2~1.4%, with the increase of the amount of water reducing agent, the compressive strength first increases and then decreases, reaching the maximum when the dosage is 1.3%, and the early drying shrinkage strain of concrete increases slightly.

1. Introduction
Self-compacting barite concrete is a new type of high-performance concrete made by mixing barite as coarse and fine aggregate with cement, admixtures and additives. It can be evenly filled into densely reinforced and complex structures without vibrating, has good fluidity and radiation resistance[1], and can be widely used in nuclear scientific research, medical treatment and nuclear power plants with radiation sources. However, self-compacting barite concrete due to the large amount of admixtures, the large amount of cementitious materials, the high amount of water reducing agent and the use of heavy aggregates, its early drying shrinkage changes are more complicated than its later stages. If it is not paid attention to, once a large number of early shrinkage cracks appear in the concrete, it may develop into penetrating and penetrating cracks in the later stage, which will seriously affect the safety and use function of the radiation-proof concrete structure. Therefore, it is necessary to study the early drying shrinkage properties of self-compacting barite concrete.

At present, there is no uniform and effective method for testing the early drying shrinkage performance of self-compacting concrete at home and abroad. In this paper, a set of measurement method for early shrinkage of self-compacting concrete is designed based on the existing conditions. Then, the development law of early dry shrinkage of self-compacting barite concrete is analyzed by this method, and the influence of the mixing ratio of mineral admixtures (fly ash F and mineral powder K)
and water reducing agent on early dry shrinkage of concrete is explored. It provides a reference for the experimental research and engineering application of self-compacting barite concrete, a new type of high-performance anti-radiation material.

2. Experiment

2.1. Raw materials
Main raw materials: Red Lion P•O 42.5 Portland cement, Barite (particle size 5~20mm, apparent density 4312kg/m³) and barite sand (after drying, the barite fine aggregate less than 0.15mm is screened out, fineness modulus 2.98, apparent density 4057kg/m³) produced in Hengyang, Hunan, A concrete mixing station poly carboxylic acid high efficiency water reducing agent (water reducing efficiency was 18%), A power plant grade II commercial fly ash and S95 grade granulated blast furnace slag powder.

2.2. Experiment method

2.2.1 Working and mechanical performance test methods
The tests of slump, slump expansion, T500, V-shaped funnel time and apparent density index are all carried out in accordance with the requirements in GB/T 50080-2016 "Standard for Test Methods for Performance of Ordinary Concrete Mixtures". The cube compressive strength test is carried out in accordance with the provisions of GBT 50081-2019 "Test Method Standard for Physical and Mechanical Properties of Concrete".

2.2.2 Early shrinkage test method
In the past, people thought that drying shrinkage was a long-term performance, but compared with ordinary concrete, self-compacting barite concrete has greatly improved its strength and compactness, which led to more concrete drying shrinkage in the early stage. Compared with the drying shrinkage measured in the later period, the research on the early drying shrinkage of self-compacting barite concrete may be more important. Moreover, the drying shrinkage measured according to the standard is not the real shrinkage, it includes the autogenous shrinkage of concrete. The shrinkage of concrete is mainly auto-shrinkage and dry shrinkage. Since the auto-shrinkage value of ordinary concrete is much smaller than its dry shrinkage value, the measured shrinkage value can be roughly regarded as the dry shrinkage value[2]. As for self-compacting concrete, its autogenous shrinkage accounts for a large proportion of the total shrinkage, which is often not negligible[3].

In this paper, referring to GB/T 50082-2009 "Standard for long-term performance and durability test methods of ordinary concrete", a set of test methods for measuring the early drying shrinkage performance of self-compacting barite concrete is improved and designed. A prism specimen with a size of 100 mm×100 mm×515 mm is used, and each measurement group has 6 specimens, which are 3 total shrinkage specimens and 3 self-shrinkage specimens. The shrinkage measurement is carried out with a concrete shrinkage and expansion tester. After these test pieces were cast, they were quickly covered with a polyvinyl chloride plastic film, and they were allowed to stand at room temperature (20±5) °C. When these concrete test blocks reach the final setting, the steel mold is removed. After the mold is removed, these total shrinkage test pieces are not processed, and these self-shrinking test pieces are immediately wrapped and sealed with plastic film. Start measuring the initial dial gauge readings of these total shrinkage specimens and self-shrinkage specimens with a shrinkage and expansion apparatus, and then place each shrinkage specimen at a constant temperature (20±5)°C and a constant humidity (60±5)% for curing. Maintenance in the room. This test is measured from the final setting (12h) of concrete to the 7d age. Measured every 6h in the first two days after the final setting of the concrete, every 8h during the 3d to 4d age period, and every 12h on the last three days. Finally, the early drying shrinkage value of self-compacting barite concrete is roughly obtained by subtracting the early autogenous shrinkage value from the total early shrinkage value of the concrete.
2.3. Mix design

Comprehensively refer to the relevant design regulations in GBT 50557-2010 "Technical Specification for the Application of Barite Radiation Protection Concrete" and NBT 20339-2015 "Technical Regulations for the Application of Self-compacting Concrete in Nuclear Power Plants", and in accordance with 30% of the total amount of mineral admixtures, the mixing ratio of mineral admixtures (fly ash F and slag K) is 3:1, 1:1, 1:3, and the mixing amount of polycarboxylic acid water reducing agent (PCE) is 1.2%, 1.3%, 1.4% designed five sets of C30 self-compacting barite concrete mix ratio. The mix proportions are shown in Table 1. A0 is the benchmark group, B1 and B2 are the admixture compound test group, and C1 and C2 are the water reducing agent test group.

| Group | Cement (kg) | Fly ash (kg) | Mineral powder (kg) | Barite sand (kg) | Water (kg) | Water reducing agent (%) |
|-------|-------------|--------------|---------------------|-----------------|------------|--------------------------|
| A0    | 336         | 108          | 36                  | 1423            | 1169       | 182                      | 6.24 |
| B1    | 336         | 72           | 72                  | 1423            | 1169       | 182                      | 6.24 |
| B2    | 336         | 36           | 108                 | 1423            | 1169       | 182                      | 6.24 |
| C1    | 336         | 108          | 36                  | 1423            | 1169       | 182                      | 5.76 |

3. Results and discussion

3.1. The working performance and compressive strength of self-compacting barite concrete

Table 2 shows the test results of the working performance of each group of self-compacting barite concrete mixtures and the compressive strength of these concrete.

| Group | Slump (mm) | Expansion (mm) | T500 (s) | V-shaped funnel /s | Apparent density /kg/m³ | Appearance description | Cube compressive strength (Mpa) |
|-------|------------|----------------|----------|-------------------|--------------------------|------------------------|-------------------------------|
| A0    | 267        | 684            | 1.9      | 11.5              | 3310                     | Good                   | 18.9 26.0 34.3               |
| B1    | 261        | 673            | 2.2      | 13.1              | 3230                     | Good                   | 20.2 27.8 33.5               |
| B2    | 253        | 654            | 2.3      | 19.4              | 3220                     | Slight segregation     | 20.8 28.4 31.9               |
| C1    | 256        | 595            | 2.6      | 23.0              | 3230                     | Good                   | 17.2 24.4 33.1               |
| C2    | 270        | 691            | 1.7      | 10.9              | 3240                     | Slight segregation     | 16.8 25.1 31.8               |

The filling property of self-compacting concrete is characterized by the slump expansion and the expansion time T500, the gap passage is characterized by the slump expansion, and the segregation resistance is characterized by the V-shaped funnel. The working performance of each group of self-compacting barite concrete mixtures prepared in the experiment meets the requirements in NBT 20339-2015 "Technical Regulations for the Application of Self-compacting Concrete in Nuclear Power Plants".

3.1.1 Influence of the proportion of fly ash and slag powder

It can be seen from Table 2 that when the total amount of fly ash and slag powder is fixed at 30%, the increase in the proportion of fly ash is beneficial to improve the fluidity and filling of concrete, and also
improves its ability to resist segregation and gap passage. With the increase of the proportion of mineral powder, the cohesive performance of concrete will be improved and its working performance will be reduced. It is worth noting that when the mixing ratio of fly ash and mineral powder is 1:3, the concrete mixture has slight bleeding. The analysis believes that the reason is that the low water demand of mineral powder reduces the total water demand of concrete cementing materials, resulting in insufficient use of mixing water\cite{4}; the compressive strength test results showed that the increase in the proportion of mineral powder is conducive to the improvement of the strength of self-compacting barite concrete in the early and mid-term, while fly ash is conducive to the improvement of its later strength is because the hydration of mineral powder is earlier than that of fly ash, but the pozzolanic activity of fly ash is fully utilized in the later stage, so the later strength of concrete is improved\cite{5}.

3.1.2 Influence of water reducing agent content

It can be seen from Table 2 that when the content of water reducing agent is between 1.2% and 1.4%, the increase in the content greatly improves the working performance of self-compacting barite concrete, and the compressive strength gets the peak value at the optimal content of 1.3%. Adding too much or too low water reducing agent will reduce the compressive strength of concrete. This is because there will be voids in the self-compacting barite concrete with low content of water-reducing agent. The incorporation of an appropriate amount of water-reducing agent can improve the workability and compactness of the concrete. In the self-compacting barite concrete with high content of water-reducing agent, slurry separation will occur, which reduces the coagulation material between the aggregates, and the compressive strength of the concrete is reduced.

3.2. The early drying shrinkage law of self-compacting barite concrete

3.2.1 Influence of the proportion of fly ash and slag powder

Figure 1(a) shows the test results of the early total shrinkage of self-compacting barite concrete prepared with different fly ash and slag mixing ratios with age. Figure 1(b) shows the test results of the early autogenous shrinkage rate of self-compacting barite concrete prepared with different fly ash and mineral powder mixing ratios with age. The early drying shrinkage of self-compacting barite concrete with the mixing ratio of fly ash and slag powder is shown in Figure 1(c). Analysis of the following:

(1) From the final setting to the 1d age, the drying shrinkage of each group of self-compacting barite concrete increased rapidly, and the shrinkage rate reached $136.1 \times 10^{-6} \text{m/m}$, $126.4 \times 10^{-6} \text{m/m}$ and $109.2 \times 10^{-6} \text{m/m}$, accounting for 58%, 66% and 62% of their respective 7d age shrinkage rates, and the subsequent growth trend is slow, which indicates that the drying shrinkage strain of self-compacting barite concrete mainly occurs in the early stage. Therefore, when preparing self-compacting barite concrete, measures should be taken to prevent its early drying shrinkage cracks from being too large.

(2) When the total amount of fly ash and mineral powder is fixed at 30%, the drying shrinkage strain of self-compacting barite concrete increases with the increase in the ratio of fly ash to mineral powder, but the increase is not the same. When the ratio of fly ash to mineral powder increases from 1:3 to 1:1, the drying shrinkage value only slightly increases; when the ratio of fly ash to mineral powder increases from 1:1 to 3:1, the dry shrinkage rate of concrete at 3d and 7d age increased from $172.6 \times 10^{-6} \text{m/m}$, $192.8 \times 10^{-6} \text{m/m}$ to $216.6 \times 10^{-6} \text{m/m}$, $233.2 \times 10^{-6} \text{m/m}$, and the increase rate reached 25.49%, 20.95%. It shows that the relative increase of mineral powder is beneficial to reduce the dry shrinkage of concrete. This is because the mineral powder particles are finer than fly ash, which can better fill the fine voids between cement particles, reduce the concrete voids. In addition, the pozzolanic activity of mineral powder is higher than that of fly ash, which makes the hydration of mineral powder earlier than fly ash, and its hydration products are filled in the voids of concrete earlier, which further improves the pore structure\cite{6}, thus reducing the drying shrinkage of self-compacting barite concrete.
3.2.2 Influence of water reducing agent content

Figure 2(a) shows the test results of the early total shrinkage of self-compacting barite concrete prepared with different water-reducing agent content with age. Figure 2(b) shows the test results of the early autogenous shrinkage rate of self-compacting barite concrete prepared with different water-reducing agent content with age. The early drying shrinkage of self-compacting barite concrete with the change of water-reducing agent content is shown in Figure 2(c). Analysis of the following:

1) In general, it is consistent with the early drying shrinkage law of the admixture compound group. The drying shrinkage in the first 1 day develops rapidly, and the drying shrinkage rate at the age of 1 day accounts for 50 to 60% of the 7 days. Since then, the speed of development has slowed.

2) At the same water-binder ratio (0.38), when the polycarboxylate water-reducing agent is in the range of 1.2~1.4%, the auto-shrinkage of self-compacting barite concrete does not change significantly with the increase of its content, and the drying shrinkage strain increases with the increase of the water reducing agent content. This is because the incorporation of water-reducing agent will release the water wrapped by the cement flocculent structure in the concrete mixture, which increases the free water content. In addition, the polycarboxylate water reducing agent has a certain air-entraining effect, which ultimately leads to an increase in the drying shrinkage of the concrete.
4. Conclusion

1) When the amount of cementing material is 480 kg/m³, select raw materials such as fly ash-S95 grade mineral powder composite mineral admixture, barite coarse and fine aggregate, and polycarboxylic acid water reducer to successfully formulate performance Good C30 self-compacting barite concrete.

2) With the increase in the proportion of fly ash, the working performance of the self-compacting barite concrete mixture and the later compressive strength of the concrete have been improved to varying degrees, while the relative increase of mineral powder will reduce its working performance, but increase the strength of concrete in the early and mid-term. When the amount of water reducing agent is between 1.2% and 1.4%, the performance of self-compacting barite concrete has been significantly improved with the increase in the amount of water reducing agent, and the compressive strength shows a tendency to increase first and then decrease, and it is optimal when the content is 1.3%.

3) As the ratio of fly ash to mineral powder increases, the drying shrinkage strain of concrete gradually increases; at the same water-binder ratio (0.38), when the polycarboxylate water-reducing agent is between 1.2% and 1.4%, the increase in its content will increase the drying shrinkage of self-compacting barite concrete.

4) The early drying shrinkage value of each group of self-compacting barite concrete is relatively large, and the drying shrinkage rate at 1 day accounts for about 50~66% of that at 7 days. Therefore, when preparing self-compacting barite concrete, measures should be taken to prevent its early drying shrinkage cracks from being too large.

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