Study on preparation and strength of high-strength micro-expansive lightweight aggregate concrete

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Abstract: Orthogonal design was used to research the effect of water cement ratio and the content of expansive agent and fiber on the compressive strength, bending strength and splitting strength of high-strength micro-expansive lightweight aggregate concrete. The optimum mixing proportion of lightweight concrete considering different strength target was determined through the integrated balance method. Results indicated that, the splitting strength and bending strength was about 0.04 times and 0.08~0.12 times as big as the compressive strength when the intensity grade of lightweight concrete was LC45 or LC50. The content of ZY expansive agent has a notable influence on compressive strength, and has certain influence on bending strength. The water cement ratio and polypropylene fiber content have no significant effect on different strength target. The optimum mixing proportion for high-strength micro-expansive lightweight aggregate concrete was that, the content of ZY expansive agent and polypropylene fiber were respectively 8% and 0.1%, and water cement ratio was 0.30. The strength grade of LC50 for the optimum mixing proportion has been achieved.

1. Introduction

Lightweight high-strength concrete has the characteristics of high strength, light weight, high flexibility and high seismic resistance, which is increasingly used in super high-rise buildings and long-span bridges [1]. Because the strength of lightweight aggregate is lower than that of conventional aggregate, the amount of cement in lightweight high-strength concrete of the same strength level is significantly higher than that of ordinary concrete, and its early and late shrinkage deformation is much larger than ordinary concrete [2,3]. The relatively high shrinkage deformation of light-weight high-strength concrete is easy to cause concrete shrinkage and cracking, which reduces the durability and safety of the concrete structure. The incorporation of polypropylene fiber and expansion agent into concrete can reduce the early plastic cracking of concrete and reduce the limiting shrinkage caused by the effects of drying and cooling, so as to improve the crack resistance of concrete the crack resistance of concrete [4,5]. Therefore, the orthogonal experiment was used to study the lightweight high-strength micro-expansion concrete mixed with expansion agent and polypropylene fiber, and the influence of ZY expansion agent, polypropylene fiber and water-cement ratio on the different strength indexes of lightweight high-strength concrete was analyzed.
2. Test raw materials and test scheme

2.1. Test raw materials
The cement used in the test: 42.5 ordinary acid cement; coarse aggregate: 900 grade 5-20mm high-quality shale ceramsite and the apparent density of loose accumulation is 810 kg/m³; fine aggregate: river sand, medium sand; admixture 2% polycarboxylate high-performance water reducing agent and a certain amount of polypropylene fiber; mixed with a certain amount of ZY-expansion agent.

2.2. Test scheme
The ceramsite is soaked in water for 4 hours, the surface moisture is taken out and dried before the concrete is prepared in order to ensure the workability of the lightweight concrete mixture. Concrete can be prepared with water-cement ratio of 0.30 and slump of 30cm-50cm. The specific ratio is shown in Table 1. In order to explore the influence of ZY expansion agent content, fiber content and water-cement ratio on the strength of lightweight concrete and reduce the number of tests, the orthogonal table L₉ was used to determine the forming and mechanical properties of concrete. The factor levels are shown in Table 2. When a certain amount of fiber and ZY expansion agent is added into concrete and the water-cement ratio is changed, the amount of coarse and fine aggregates in concrete and the amount of total cementitious material remain unchanged, while the amount of water consumption changes.

Concrete cube specimens of 100 mm×100 mm×100 mm and prism specimens of 100 mm×100 mm×400 mm were used in the test. After 28 days of standard curing, the compressive strength, splitting tensile strength and bending strength were measured in accordance with GB/T 50081-2002 Standard for Testing Methods for Mechanical Properties of Ordinary Concrete.

Table 1 The specific ratio of concrete

| water-cement ratio | water | cement | sand | Lightweight aggregate | ZY expansion agent | fiber | water reducer |
|--------------------|------|--------|------|------------------------|-------------------|------|---------------|
| 0.30               | 150  | 500    | 696  | 684                    | 0                 | 0    | 10            |

Table 2 The factor levels of test

| level | factor | A       | B       | C       |
|-------|--------|---------|---------|---------|
| 1     | 5%     | 0.1%    | 0.28    |
| 2     | 8%     | 0.14%   | 0.30    |
| 3     | 12%    | 0.2%    | 0.32    |

Table 3 The schemes and results of test

| number | combination | ZY expansion agent | fiber | water-cement ratio | dry apparent density (kg/m³) | compressive strength (MPa) | splitting tensile strength (MPa) | bending strength (MPa) |
|--------|-------------|--------------------|------|--------------------|-------------------------------|---------------------------|-------------------------------|-----------------------|
| 0      |             | 0                  | 0    | 0.30               | 0                             | 1990                      | 47.7                          | 2.5                   | 5.53                  |
| 1      | A₁B₁C₁      | 1 (5%)             | 1 (0.1%) | 1 (0.28) | 1                      | 1953                      | 56.2                          | 1.8                   | 5.2                   |
| 2      | A₁B₂C₂      | 1 (5%)             | 2 (0.14%) | 2 (0.30) | 2                      | 1970                      | 55.8                          | 1.9                   | 4.5                   |
| 3      | A₁B₃C₃      | 1 (5%)             | 3 (0.2%) | 3 (0.32) | 3                      | 1987                      | 53.3                          | 2.2                   | 4.1                   |
3.1. Influence of water-cement ratio on strength of lightweight concrete

The relationship between compressive strength, bending strength, splitting tensile strength and water-cement ratio of lightweight concrete is shown in Figure 1. The compressive strength of concrete does not decrease with the increase of water-cement ratio, but reaches the maximum when the water-cement ratio is 0.30. On the contrary, the splitting tensile strength increases with the increase of water-cement ratio. The bending strength decreases with the increase of water-cement ratio. Although the influence of water-cement ratio on different strength indexes is different, the corresponding strength indexes with different water-cement ratio have little difference, which may be caused by the small change of water-cement ratio.

3.2. Influence of fiber content on strength of lightweight concrete

The relationship between the compressive strength, bending strength, splitting tensile strength and fiber content of lightweight concrete is shown in Figure 2. From Fig. 2, each strength index of concrete decreases with increase of fiber content. When the fiber content is increased from 0.1% to 0.2% the compressive strength decreases by 2.1%, the split tensile strength decreases by 28%, and the flexural strength decreases by 10.5%. It can be seen that the increase of fiber content has a negative effect on the strength of concrete, especially on the splitting tensile strength, which is corresponding to the results of the range analysis. Therefore, it is necessary to control the fiber content within 0.1%.

3.3. Influence of ZY expansion agent content on strength of lightweight concrete

The relationship between the compressive strength, bending strength and splitting tensile strength of lightweight concrete and ZY expansive agent is shown in Figure 3. It can be seen from Figure 3 that...
with the increase of the content of expansion agent, the compressive strength increases first and then slightly decreases, the splitting tensile strength decreases first and then increases, and the bending strength increases first and then decreases. Considering the compressive strength and bending strength, the content of ZY expansion agent should be controlled within 8%. ZY expansion agent is a calcium sulfoaluminate expansion agent. It is mixed into concrete to form hydrated calcium sulfoaluminate, which can fill the pores in concrete and generate moderate expansive force (prestress) in concrete to offset the shrinkage force formed in the hardening process of concrete, thus improving the strength and crack resistance. However, when the amount of expansion agent is more than 8%, the expansion force is too large, which reduces the compressive strength and bending strength of concrete.

![Figure 3](image1.png)  
**Figure 3** Influence of ZY expansion agent content on strength of lightweight concrete

### 3.4. Relationship among strength indexes of lightweight high-strength concrete

In the orthogonal test, the measured compressive strength values of the concrete with each ratio are greater than 50MPa, so the concrete with each ratio is regarded as LC45~LC50 lightweight high-strength concrete. The relationship between its splitting tensile strength, bending strength and compressive strength is analyzed. It can be seen from Figure 4 that the correlation between the splitting tensile strength and the compressive strength of lightweight high-strength concrete is weak but the bending strength increases significantly with the increase of the compressive strength, which indicates the correlation between them is strong. In this test, the splitting tensile strength of lightweight high-strength concrete is low, which is about 0.04 times of the compressive strength. The distribution of the ratio of bending strength to compressive strength is about 0.08~0.11.

![Figure 4](image2.png)  
**Figure 4** The relationship between the splitting tensile strength, bending strength and compressive strength

### 3.5. Range analysis of orthogonal experiment results

The range analysis was carried out according to the results of the orthogonal experiment, and the calculation results are shown in Table 4. It can be seen from Table 4 that when the strength index of orthogonal test is different, the optimal combination of each influencing factor level is different. In this paper, the comprehensive balance method is adopted to determine the optimal scheme of the test. ZY
expansion agent content is important for both compressive strength and bending strength, so $A_2$ is the best choice. However, ZY expansion agent content is second to split tensile strength, there is not much difference between $A_2$ and $A_3$. Therefore, $A_2$ can be chosen according to the majority preference. For the three indicators, fiber content $B_1$ is the best level. To water-cement ratio: $C_2$ is better for compressive strength and $C_3$ is better for split tensile strength, while $C_1$ is better for bending strength. Actually the level of water-cement ratio has no significant effect on splitting tensile strength and bending strength, so $C_2$ is chosen. Based on the comprehensive equilibrium of analysis results, the optimal test scheme is $A_2B_1C_2$. The optimal scheme is consistent with the test scheme in Table 3 where the strength index values are the maximum. Each strength index is the maximum when the ZY expansion agent content is 8%, the fiber content is 0.1% and the water-cement ratio is 0.30.

| Table 4 | The range analysis of orthogonal experiment results |
|---------|-------------------------------------------------------|
| item    | compressive strength | split tensile strength | bending strength |
|         | A  | B  | C  | A  | B  | C  | A  | B  | C  |
| K1      | 165.3 | 173.00 | 172.05 | 171.25 | 5.9 | 7.10 | 5.60 | 5.90 | 13.8 | 17.20 | 17.30 | 16.90 |
| K2      | 174.01 | 170.64 | 172.55 | 171.91 | 7.50 | 5.20 | 6.20 | 5.90 | 15.3 | 17.00 | 16.60 | 15.70 |
| K3      | 173.69 | 169.36 | 168.40 | 169.84 | 7.00 | 6.10 | 7.30 | 7.30 | 17.50 | 15.40 | 15.70 | 17.00 |
| range R | 8.71 | 3.64 | 4.15 | 2.08 | 1.80 | 1.90 | 1.70 | 1.40 | 4.50 | 1.80 | 1.60 | 1.30 |
| factor order | $A_2$, $C_1$, $B_3$ | $B_1$, $A_3$, $C_1$ | $A_2$, $B_3$, $C_1$ |

3.6. Variance analysis of orthogonal test results

Since the range analysis could not estimate the inevitable error size in the test process and test result measurement, the analysis conclusion was not accurate enough. Then the variance analysis of the test results was carried out, and the results are shown in Table 5. It can be seen from Table 5 that the content of ZY expansion agent has a significant influence on the compressive strength of lightweight concrete and a certain influence on the bending strength. Fiber content and water-cement ratio had no significant effect on the three test indexes. As it is better when the strength value of concrete is higher, $A_2$ is the best level for the content of ZY expansion agent. For the water-cement ratio and fiber content, the choice should be made according to the workability and economy of concrete mixture. With the increase of fiber content, the fluidity of concrete mixture decreases accordingly, so level $B_1$ is taken. When the water-cement ratio is too low, the water consumption will decrease and the cement dosage will increase, and the fluidity and economy of the concrete mixture will become worse. Considering the influence of the water-cement ratio on the strength, fluidity and economy of concrete, level $C_2$ is taken. The optimal combination is consistent with the optimal test scheme $A_2B_1C_2$ determined by range analysis. Compared with the reference concrete with a water-cement ratio of 0.30, the compressive strength of lightweight concrete with the addition of 8% ZY expansive agent and 0.1% fiber is significantly increased, the bending strength is slightly increased and the splitting tensile strength is slightly decreased. The experimental results confirm that the addition of ZY expansion agent can significantly improve the compressive strength of lightweight concrete, slightly enhance the bending strength and have little effect on the splitting tensile strength.

| Table 5 | The variance analysis of orthogonal experiment results |
|---------|-------------------------------------------------------|
| variance | compressive strength | split tensile strength | bending strength |
| sum of squares | DOF | mean square | F | sum of squares | DOF | mean square | F | sum of squares | DOF | mean square | F |
| A        | 16.26 | 2 | 8.13 | 21.83* | 0.65 | 2 | 0.33 | 1.49 | 3.84 | 2 | 1.92 | 11(*) |
| B        | 2.27 | 2 | 1.14 | 3.05 | 0.7 | 2 | 0.35 | 1.6 | 0.65 | 2 | 0.325 | 1.86 |
| C        | 3.42 | 2 | 1.71 | 4.59 | 0.5 | 2 | 0.25 | 1.14 | 0.43 | 2 | 0.215 | 1.23 |
| error    | 0.76 | 2 | 0.37 | 0.46 | 0.23 | 0.35 | 0.175 |

$F_{0.05(2,2)}=99.01$, $F_{0.05(2,2)}=19.00$, $F_{0.05(2,2)}=9.00$. The optimal combination is $A_2B_1C_2$. The optimal scheme is consistent with the test scheme in Table 3 where the strength index values are the maximum. Each strength index is the maximum when the ZY expansion agent content is 8%, the fiber content is 0.1% and the water-cement ratio is 0.30.
4. Conclusion

Through the orthogonal experimental research, the following conclusions are drawn:

(1) When the water-cement ratio varies from 0.28 to 0.32, the difference of the strength indexes of lightweight concrete is small. The increase of fiber content will reduce the strength indexes of lightweight concrete, so the fiber content is limited to 0.1%. Each strength index of concrete presents a different trend with the increase of the content of ZY expansion agent. Considering the compressive strength and bending strength, the content of ZY expansion agent should be controlled within 0.8%.

(2) The range analysis of the orthogonal test results shows that the order of the influencing factors is not consistent when the strength indexes of lightweight concrete are different. Considering the influence of various factors on different strength indexes, the optimal test scheme of lightweight concrete is determined as follows: 8% ZY expansion agent, 0.1% fiber and water cement ratio of 0.30. The strength grade of lightweight concrete corresponding to the optimal ratio can reach LC50.

(3) The variance analysis of the orthogonal test results shows that the content of ZY expansion agent has a significant effect on the compressive strength of lightweight concrete and a certain effect on the bending strength, but has no significant effect on the splitting tensile strength.

(4) When the strength grade of lightweight high-strength concrete is LC45~LC50, the splitting tensile strength is about 0.04 times of the compressive strength, and the bending strength is about 0.08~0.12 times of the compressive strength.

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