Research on Freeze-Thaw Cycles of Expansive Concrete in Civil and Repairing Engineering

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Abstract. In this paper, large areas of defects such as pitting surface and holes produced after pouring concrete in civil engineering are simulated. The orthogonal method is used to produce expansive concrete which has a higher strength grade and a smaller aggregate size than original concrete for repairing. The effects of different water reducing agent content, expansive agent content, fly ash content and sand ratio on freeze-thaw cycle are analyzed. Finally, it recommends the best concrete mixing proportion and verifies repairing effect by comparing with original concrete of nonrepair. Results indicate that the mixing proportion which means 5% expansive agent content, 1.2% water reducing agent content, 20% fly ash content and 30% sand rate can obtain good antifreeze effect. In addition, the influence of water reducing agent on freeze-thaw effect is more obvious than expansive agent. Moreover, a greater content of expansive agent can not lead to a better effect of freeze-thaw cycles.

1. Introduction
At present, the largest amount of concrete is used in civil engineering construction materials[1]-[3]. However, many defects of concrete buildings such as large areas of voids and pits, holes may appear owing to design problems, construction technology problems, improper maintenance and other reasons[4]-[6]. It is of great possibilities that they will cause direct or indirect harms to concrete buildings, which even lead to the buildings’ failures to reach the expected service life and result in great economic loss and waste resources[7]-[10]. In view of the above problems, the authors put forward a innovative idea that expansive concrete can be used to repair defects with the aim to improve the “three-grade strengthening effect” after hydration of cement, fly ash and expansive agent, and to polish up the compactness of concrete after repairing. The authors also hope to provide basic support and scientific basis for the durability research of concrete concerning civil and repairing engineering.

2. Experiment Materials and Schemes

2.1 Experiment materials
In this experiment, cement grade was P·O42.5. Dilated anti-cracking and waterproof agent was used as expansive agent. Fly ash was grade II. River sand was used as fine aggregate. The coarse aggregate was consisted of two kinds of stones: small stones (diameter:5 ~ 20mm), medium stones (diameter:20 ~ 40mm). Water reducing agent was high-performance water reducing agent(DH13). The type of air-entraining agent was DH9.
2.2 Experiment schemes

Ordinary concrete (original concrete) was made of 2 grade gravel (5 ~ 20mm, 20 ~ 40mm), and its strength grade was designed to be C30. Besides, the size of specimen was 100mm x 100mm x 400mm. After the concrete specimen was molded into 28d, the defective concrete was cut out by means of machine and artificial combination, so that specimen could form regular 'square groove'[15]-[16]. As shown below, specific size of square groove specimen was drawing in Figure 1. The expansive concrete used for repair was 1-grade gravel (5 ~ 20mm), and its strength grade was C35, its repairing procedure was shown by Figure 2.

Orthogonal and combinational design was used for expansive concrete, orthogonal test table L₉(3⁴) was selected from statistics. As follows, the parameters of factors level were shown by Table 1, and concrete proportioning was shown by Table 2. The effects of different water reducing agent content, expansive agent content, fly ash content and sand ratio on freeze-thaw cycle were analyzed on the basis of ordinary concrete(C30). The best antifreeze mixture ratio would obtain by analysis. To verify whether there was a good repairing effect in frost resistance, the frost resistance of the repairing concrete specimens was compared with the normal concrete specimens without defects in 90d.

| Factors               | Level | A(fly ash content /%) | B(expansive agent content /%) | C(water reducing agent content /%) | D(sand ratio /%) |
|-----------------------|-------|-----------------------|--------------------------------|------------------------------------|-----------------|
|                       | 1     | 15                    | 4                              | 0.8                                | 30              |
|                       | 2     | 20                    | 5                              | 1.0                                | 35              |
|                       | 3     | 25                    | 6                              | 1.2                                | 40              |
Table 2. Design parameters of concrete proportioning

| Number | A   | B   | C   | D   | Water (kg/m³) | Cement (kg/m³) | Fly ash (kg/m³) | Sand (kg/m³) | Small stone (kg/m³) | Medium stone (kg/m³) | Expansive agent (kg/m³) | Water reducing agent (kg/m³) | Air-entraining agent (kg/m³) |
|--------|-----|-----|-----|-----|---------------|----------------|----------------|--------------|---------------------|---------------------|-----------------------------|-------------------------------|-----------------------------|
| F1     | 15% | 4%  | 0.8%| 30% | 160           | 324            | 60             | 552          | 1288                | 0                   | 16                         | 3.2                           | 0.032                        |
| F2     | 15% | 5%  | 1.0%| 35% | 160           | 320            | 60             | 644          | 1196                | 0                   | 20                         | 4.0                           | 0.032                        |
| F3     | 15% | 6%  | 1.2%| 40% | 160           | 316            | 60             | 736          | 1104                | 0                   | 24                         | 4.8                           | 0.032                        |
| F4     | 20% | 4%  | 1.0%| 40% | 160           | 304            | 80             | 736          | 1104                | 0                   | 16                         | 4.0                           | 0.032                        |
| F5     | 20% | 5%  | 1.2%| 30% | 160           | 300            | 80             | 552          | 1288                | 0                   | 20                         | 4.8                           | 0.032                        |
| F6     | 20% | 6%  | 0.8%| 35% | 160           | 296            | 80             | 644          | 1196                | 0                   | 24                         | 3.2                           | 0.032                        |
| F7     | 25% | 4%  | 1.2%| 35% | 160           | 284            | 100            | 644          | 1196                | 0                   | 16                         | 4.8                           | 0.032                        |
| F8     | 25% | 5%  | 0.8%| 40% | 160           | 280            | 100            | 736          | 1104                | 0                   | 20                         | 3.2                           | 0.032                        |
| F9     | 25% | 6%  | 1.0%| 30% | 160           | 276            | 100            | 552          | 1288                | 0                   | 24                         | 4.0                           | 0.032                        |
| Y      | 20% | 0   | 1.0%| 34% | 145           | 258            | 64             | 657          | 510                 | 766                 | 0                           | 3.22                          | 0.026                        |

Remarks: Expansive concrete proportioning is F1-F9 (C35). Ordinary concrete proportioning is Y (C30).

2.3 Experimental method

Rapid freeze-thaw method was adopted in repaired specimens. The test instruments were dynamic modulus tester (DT-8W) and concrete freeze-thaw tester (CDR-2). The experiment was based on SL352-2006[17], and specimens used for testing were soaked in water 4 days in advance (water temperature: 20±3°C) after repairing for 90 days. At the time of experiment, it needed to wipe off the initial weight of the water on the surface of specimens and measured transverse natural frequency. When the natural frequency was measuring, a layer of vaseline was used as coupling medium between measuring rod and specimen. The pressure of the measuring rod was the best without noise[18]. The gain of vibration pickup and vibration exciter was adjusted by the resonant frequency of specimen. When the maximum indication value of oscilloscope tube was considered to be resonant, the frequency of digital counter was self-vibration frequency of specimen. The frequency was generally repeated two times, and its absolute error value was 0.5%. Then the specimens were loaded into a box and injected into fresh water (the top of submergence test piece was about 20mm), then the instrument was turned on for testing. As below the specific test process was shown by figure 3.
Figure 3. A schematic diagram of 90d freeze-thaw test of specimens

(1) The relative dynamic elastic modulus of the specimen is calculated by Formula (1-1), and the average value of testing results of a group (3 blocks) is taken as the measured value.

\[ P_n = \frac{f_n^2}{f_o^2} \times 100 \]  \hspace{1cm} (1-1)

Among them, \( P_n \) is relative dynamic elastic modulus after freezing and thawing for \( n \) times (unit:%), \( f_n \) is natural vibration frequency of specimens after freezing and thawing for \( n \) times (unit: Hz), \( f_o \) is natural vibration frequency of specimens before freezing and thawing (unit: Hz).

(2) The mass loss rate of the specimen is calculated by Formula (1-2), and the average value of a set of testing results is taken as the measured value.

\[ W_n = \frac{(G_o - G_n)}{G_o} \times 100 \]  \hspace{1cm} (1-2)

Among them, \( W_n \) is the mass loss rate after freezing and thawing for \( n \) times (unit:%), \( G_o \) is the quality of specimen before freezing and thawing (unit:g), \( G_n \) is the quality of specimen after freezing and thawing for \( n \) times (unit:g).

(3) Results are evaluated according to the following criteria.

If the specimen of freezing and thawing cycles runs up to 150 times of design, at the same time, mass loss rate of the specimen is less than 5%, and relative dynamic elastic modulus is less than 60%.
of initial value. It is considered that the specimen has been satisfied with the designed requirement[19].

2.4 Experimental results
Based on the above methods and formulas, test results of 90d specimens made of expansive concrete and ordinary concrete specimens without defects are shown by Table 3.

| Number | Relative dynamic elastic modulus (Pn) /Mass loss rate (Wn) (unit:%) |
|--------|---------------------------------------------------------------|
|        | 0 time 25 times 50 times 75 times 100 times 125 times 150 times |
| Y      | 100/0 99.2/0.06 99.0/0.08 98.3/0.09 96.2/0.10 92.8/0.11 87.8/1.99 |
| F1     | 100/0 99.3/-0.03 95.2/0 92.7/0.24 86.5/0.68 80.9/1.11 74.4/1.23 |
| F2     | 100/0 99.1/0.14 98.3/0.38 96.4/0.49 94.0/0.68 87.2/1.24 82.2/1.31 |
| F3     | 100/0 99.4/-0.02 98.2/0.16 95.3/0.18 92.1/0.20 86.1/0.67 81.1/2.54 |
| F4     | 100/0 98.4/-0.01 96.1/-0.05 94.6/-0.14 92.1/-0.09 87.7/0.17 82.7/0.26 |
| F5     | 100/0 99.6/0.5 99.3/0.65 98.6/0.66 96.7/0.68 93.2/0.85 89.2/0.86 |
| F6     | 100/0 99.1/-0.04 96.2/-0.09 93.5/-0.12 86.7/-0.10 81.9/0 76.9/0.01 |
| F7     | 100/0 98.6/-0.06 95.6/-0.10 93.2/-0.14 91.1/-0.19 85.8/-0.04 80.8/0.01 |
| F8     | 100/0 99.2/0.26 97.3/0.36 93.9/0.41 90.4/0.48 86.3/0.92 81.3/0.97 |
| F9     | 100/0 99.4/-0.10 98.5/-0.11 96.3/-0.15 95.0/-0.19 91.8/-0.10 85.8/0 |

The above test results show that the mass loss rates of F3, F4, F6, F7 and F9 groups just start to be negative and gradually turn to positive value. The mass loss rate is negative, indicating that concrete specimens do not produce denudation[20]. On the contrary, its mass increases with the growing of water absorption. The mass loss rate gradually becomes positive, indicating that there is higher level of erosion to repaired concrete specimens.

3. Analysis of experiment results

3.1 The max-min difference analysis
According to the data in Table 3, max-min difference values which are about relative dynamic elastic modulus of expansive concrete after 150 times freeze-thaw cycles between A (fly ash), B (expansive agent), C (water reducing agent) and D (sand ratio) are calculated. Because the proportion, shape and size of defects of ordinary concrete remain the same, max-min difference value of relative dynamic elastic modulus is considered to be of expansive concrete. Relative dynamic elastic modulus range of expansive concrete after 150 freeze-thaw cycles are shown by Table 4.
Table 4. Analysis of relative dynamic elastic modulus range of expansive concrete after 150 freeze-thaw cycles

| Level | Number | A  | B  | C  | D  | Relative dynamic elastic modulus (%) |
|-------|--------|----|----|----|----|-------------------------------------|
| 1     | 1      | 1  | 1  | 1  | 1  | 74.4                                |
| 2     | 1      | 2  | 1  | 2  | 2  | 82.2                                |
| 3     | 1      | 3  | 2  | 2  | 3  | 81.1                                |
| 4     | 2      | 2  | 3  | 2  | 3  | 82.7                                |
| 5     | 2      | 3  | 2  | 3  | 1  | 89.2                                |
| 6     | 2      | 3  | 1  | 2  | 1  | 76.9                                |
| 7     | 3      | 2  | 1  | 3  | 2  | 80.8                                |
| 8     | 3      | 2  | 2  | 1  | 3  | 81.3                                |
| 9     | 3      | 3  | 2  | 1  | 3  | 85.8                                |
| Ij    |        | 237.7 | 237.9 | 232.6 | 249.4 |                                    |
| IIj   |        | 248.8 | 252.7 | 250.7 | 239.9 |                                    |
| IIIj  |        | 247.9 | 243.8 | 251.1 | 245.1 |                                    |
| Rj    |        | 11.1  | 14.8 | 18.5 | 9.5 |                                    |

According to Table 4, the order of relative elastic modulus of expansive concrete 90d after freezing and thawing is C>B>A>D (water reducing agent > expansive agent > fly ash > sand rate).

3.2 Point graph analysis

Point graph 4 is drawn to intuitively analyze the effect of fly ash, expansive agent, water reducing agent and sand rate on frost resistance of expansive concrete, and to recommend best concrete proportioning.
3.3 Analysis of the relationship between freeze-thaw times and relative dynamic elastic modulus

According to the data in Table 3, the relative dynamic modulus of factor 1-factor 4 of the expansive agent is calculated respectively, as shown in Figure 5.

As shown by Figure 5, with the increase of the number of freeze-thaw times, the anti-freezing
effect of 5% expansive agent is better. In addition, with the increase of expansive agent content, anti-freezing effect gradually decreases.

3.4 Analysis of repairing effect
According to the optimum principle of the orthogonal experiment, the relative dynamic elastic modulus of repairing concrete specimens of F5 and the one of the ordinary concrete specimens without defects are compared after 90 days. It is found that the relative dynamic elastic modulus of concrete specimens of F5 is 5.6% higher than that of the ordinary concrete specimens without defects. It shows that this repair has achieved a good anti-freezing effect.

4. Conclusions
(1) The influence of water reducing agent on frost resistance of expansive concrete is greater than that of the expansive agent and other factors.
(2) Through orthogonal analysis, the optimum concrete proportioning of 90d's freeze-thaw cycles is A2B2C3D1 (fly ash content is 20%, expansive agent content is 5%, water reducing agent content is 1.2%, sand rate is 30%). Compared with original concrete, the relative dynamic elastic modulus of concrete specimens after repairing has been greatly improved. It shows that the application of expansive concrete to repair civil concrete's defects can achieve better anti-freezing effect.
(3) A greater content of expansive agent can not achieve better effect of freeze-thaw cycles.

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