Research and application for key technology of anti-cracking of acrylic emulsion mortar

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Abstract. Acrylic emulsion mortar is an ideal material of repair and reinforcement for concrete anti-carbonation and erosion, and it has been widely used in the reinforcement of culvert and sluice in recent years. When it is used, shrinkage stress occurs inside the mortar. Once this shrinkage stress exceeds the tensile strength of the mortar, cracks will appear in the mortar, which will seriously affect the construction quality and increase the repair rate or warranty workload. In this paper, the key technology of anti-cracking of acrylic emulsion mortar is studied, characteristic is analyzed of acrylic emulsion mortar protection, and various anti-cracking parameters are proposed. This key technology is verified through the application in the Dongchi sluice reinforcement project. When the technology has achieved economic benefits, it also achieved social benefits. In the future, the application prospects of the key technology of acrylic emulsion mortar anti-cracking in the culvert and sluice reinforcement project in the Yellow River Basin are very broad.

1. Project research purpose
As a new type of repair material for concrete buildings, acrylic emulsion mortar is widely used in culverts and sluices in the Yellow River flood control project with its excellent impermeability, tensile performance, and bonding ability. However, some defects in the material, such as cracks and crazing, were gradually discovered during the repair and use. This is because the acrylic emulsion mortar shrinks due to water loss during its condensing and hardening process in use. When this shrinkage stress is constrained by the matrix, shrinkage stress will be generated inside the mortar. Once this shrinkage stress exceeds the tensile strength of the mortar, the mortar will crack, which will have a serious impact on the quality of construction and increase the repair rate or warranty workload. [1-2] The purpose of this paper is to conduct system analysis through a professional laboratory combined with on-site implementation operations, analyze various influencing factors, propose various anti-cracking parameters, research reasonable anti-cracking measures, and calculate economic benefits. And in the future, it will be popularized and applied in culvert and sluice reinforcement project in the Yellow River Basin in the "14th Five-Year Plan" period.

2. Project research background
Dongchi Sluice is located at No. 40+522 of Beijindi Stake in Shen County, Liaocheng City, Shandong Province. It was built in 1979. In May 2009, the relevant expert team of the Shandong River Affairs Bureau conducted a safety appraisal of the Dongchi Sluice. The safety appraisal was classified as the third type of sluices. One of the appraisal conclusions was that the pier head and the surface of the culvert concrete were freeze-thaw damage and carbonization. In 2015, the Dongchi Sluice began to
implement the danger-removing and strengthening project, one of the contents is the use of acrylate mortar to repair the surface defects of the pier and the culvert concrete shedding. Research for the key technology of anti-cracking of acrylic-sand mortar was developed based on the above project.

3. Project research route

3.1. The main advantages of acrylic mortar

Acrylic emulsion mortar is the abbreviation for acrylic copolymer emulsion cement mortar, which belongs to high molecular polymer emulsion modified cement mortar. Acrylic emulsion mortar is a new type of repair material for concrete buildings. It has a lot of performance such as excellent adhesion, crack resistance, water resistance, chloride ion penetration, wear resistance, and aging resistance. It also has many advantages, low cost, convenient construction, adapting well to the base concrete temperature, anti-air aging and others.

3.2. Analysis on the factors of cracks in acrylic emulsion mortar

The overall displacement of the structure, especially uneven settlement, will cause settlement cracks and structural cracks in the concrete structure. The causes of cracks appearing in the concrete structure include temperature cracks, shrinkage cracks, steel corrosion cracks, alkali aggregate reaction cracks, construction cracks, etc. Shrinkage is one of the important reasons that cause cracks in the acrylic emulsion mortar, resulting in a decrease in durability. Studying the factors affecting the shrinkage performance of acrylic emulsion mortar has guiding significance on how to inhibit and reduce the shrinkage of acrylic emulsion mortar. The factors affecting the shrinkage of cement mortar are internal and external reasons. Internal factors refer to cement matrix parameters: water-cement ratio, lime-sand ratio, cement fineness, cement type, mineral admixtures, emulsion content and admixtures. External factors mainly refer to environmental conditions: curing time before drying, curing temperature, drying conditions, and relative humidity of the environment. [1-2]

3.3. Research route design [3-4]

Figure 1. Project research flow chart.
After preliminary understanding and repeated research on the performance of acrylate mortar, the project research route is drawn up as Figure 1.

### 4. Experimental process

#### 4.1. Laboratory test process

The laboratory test flow chart is drawn up as Figure 2.

![Figure 2. Laboratory test flow chart.](image)

The field test flow chart is drawn up as Figure 3.

![Figure 3. Field test flow chart.](image)

4.1.1. **Main test items.** Through the experimental analysis, the modification effect of acrylic emulsion mortar under different mix ratios (water-cement ratio), and at the same time examine whether the curing methods match.

The three influencing factors on the shrinkage rate of acrylic emulsion mortar are the curing temperature before drying, the curing time before drying, and the curing humidity during drying. The influence of each factor is grouped as follows:

1) the curing temperature before drying (3 sets of test pieces: 10°C, 20°C, 40°C)
2) the curing time before drying (3 sets of test pieces: 1d, 2d, 4d)
3) the curing humidity during drying (3 sets of test pieces: 45%, 70%, 90%)

4.1.2. **Mix ratio.** The conclusion of this mix ratio design test is that the ratio of acrylic emulsion mortar is cement: sand: polyacrylate emulsion: water = 100:150:31:14.

4.2. **Experimental process [3-4]**

4.2.1. **Specimen production.** For each influencing factor, three sets of test pieces are set up and named in the form of X-X-X. The name of each group of specimens starts with the initials of the Chinese Pinyin of the influencing factors, which are temperature (W), days (T), and humidity (S). The different levels of the same influencing factor are taken as the second number, and the three specimens of each level are named 1, 2, and 3. For example, W-10-1, it means that the main factor affecting of the mortar shrinkage is the curing temperature before drying, the specimen numbered 1 in the group of specimens with a curing temperature of 10°C. A total of 27 sets of specimens were made, corresponding to the curing temperature of 10°C, 20°C, and 40°C, corresponding to the curing days of 1d, 2d, 4d, corresponding to the curing humidity of 40%, 75%, 90%, the permutation and combination of various factors and are made and then shrinkage test would be carried out.
4.2.2. *The result of the test.* a. Test results of acrylic emulsion mortar under different curing temperatures

The correlation formula between the shrinkage rate and age of acrylic emulsion mortar was obtained by numerical fitting from the test data under different curing temperatures before drying.

Using polynomial fitting method, the correlation formulas of age $x$ and shrinkage rate $y$ under curing conditions of $10^\circ$, $20^\circ$ and $40^\circ$ are obtained respectively.

- $10^\circ$: $y = -7E-07x^2 + 4E-05x + 2E-05$
- $20^\circ$: $y = -6E-07x^2 + 3E-05x + 9E-06$
- $40^\circ$: $y = -4E-07x^2 + 3E-05x - 2E-06$

The shrinkage curve and three fitting curves of mortar under different curing temperatures are as Figure 4-7. The dry shrinkage rate is as Table 1.

![Shrinkage curve of mortar with different curing temperature.](image1)

**Figure 4.** Shrinkage curve of mortar with different curing temperature.

![Fitting curve of age $x$ and shrinkage rate $y$ under $10^\circ$ curing condition.](image2)

**Figure 5.** Fitting curve of age $x$ and shrinkage rate $y$ under $10^\circ$ curing condition.

![Fitting curve of age $x$ and shrinkage rate $y$ under $20^\circ$ curing condition.](image3)

**Figure 6.** Fitting curve of age $x$ and shrinkage rate $y$ under $20^\circ$ curing condition.

![Fitting curve of age $x$ and shrinkage rate $y$ under $40^\circ$ curing condition.](image4)

**Figure 7.** Fitting curve of age $x$ and shrinkage rate $y$ under $40^\circ$ curing condition.

| curing temperature/days | 7d   | 14d  | 21d  | 28d  | 35d  |
|-------------------------|------|------|------|------|------|
| $10^\circ$              | 100% | 100% | 100% | 100% | 100% |
| $20^\circ$              | 82.14% | 84.78% | 92.16% | 96.23% | 96.36% |
| $40^\circ$              | 57.14% | 73.91% | 76.47% | 83.02% | 83.64% |

b. Test results of acrylic emulsion mortar under different curing days

The correlation formula between the shrinkage rate and age of acrylic emulsion mortar was obtained by numerical fitting from the test data under different curing time before drying.

Using polynomial fitting method, the correlation formulas of age $x$ and shrinkage rate $y$ under curing conditions of 1d, 2d and 4d are obtained respectively.
The shrinkage curve and three fitting curves of mortar under different curing time are as Figure 8-11. The dry shrinkage rate is as Table 2.

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**Figure 8.** Shrinkage curve of mortar with different curing time.

**Figure 9.** Fitting curve of age x and shrinkage rate y under 1d curing condition.

**Figure 10.** Fitting curve of age x and shrinkage rate y under 2d curing condition.

**Figure 11.** Fitting curve of age x and shrinkage rate y under 4d curing condition.

**Table 2.** Reduction rate of shrinkage.

| curing days/days | 7d    | 14d   | 21d  | 28d  | 35d  |
|------------------|-------|-------|------|------|------|
| 1d               | 100%  | 100%  | 100% | 100% | 100% |
| 2d               | 104.35% | 92.31% | 101.96% | 100.00% | 100.00% |
| 4d               | 113.04% | 97.44% | 101.96% | 100.00% | 101.89% |

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c. Test results of acrylic emulsion mortar under different curing humidity

The correlation formula between the shrinkage rate and age of acrylic emulsion mortar was obtained by numerical fitting from the test data under different curing humidity during drying.

Using polynomial fitting method, the correlation formulas of age x and shrinkage rate y under curing conditions of 40%, 75% and 90% humidity are obtained respectively.

40%: \[ y = -6E-07x^2 + 4E-05x + 1E-06 \]

75%: \[ y = -6E-07x^2 + 4E-05x + 3E-06 \]

90%: \[ y = -6E-07x^2 + 4E-05x + 1E-05 \]

The shrinkage curve and three fitting curves of mortar under different curing time are as Figure 12-15. The dry shrinkage rate is as Table 3.
4.3. Implementation on-site

According to the data provided by the laboratory, the designed repair method is improved in the construction details, time nodes, construction technology, and construction process. Repair the surface defects of concrete shedding of the pier, culvert body and roof of Dongchi Sluice from the following aspects: cutting off the old concrete erosion layer before construction, mixing acrylate mortar, layering paving when mortaring, the culvert divided into construction unit blocks, and the mortar surface immediately covered with plastic film after the wiping off [5]. On May 1, 2016, the construction of the acryl emulsion mortar for reinforcement of Dongchi Sluice began; on June 1, 2016, the construction of the acryl emulsion mortar project was completed; January 11, 2017, it was passed the unit engineering acceptance; May 25, 2017, there was no cracks appeared after one year.

5. Project test conclusion

1. The water-cement ratio is one of the main parameters affecting the shrinkage and deformation of acrylic emulsion cement mortar. Reducing the water-cement ratio can reduce the shrinkage and tensile stress of the acrylic emulsion cement mortar, thereby improving the crack resistance of the mortar. The water-cement ratio is recommended to be 0.35-0.45 during construction.

2. Temperature influence analysis: When the curing temperature of acrylic emulsion mortar is more than 20℃, the shrinkage rate gradually decreases. In view of the permitting degree of construction conditions, the temperature of construction and maintenance should be controlled at 30℃±5℃.

Table 3. Reduction rate of shrinkage.

| humidity/days | 7d  | 14d | 21d | 28d | 35d |
|---------------|-----|-----|-----|-----|-----|
| 40%           | 100%| 100%| 100%| 100%| 100%|
| 75%           | 66.67%| 84.09%| 83.02%| 82.76%| 85.00%|
| 90%           | 40.00%| 52.27%| 56.60%| 58.62%| 61.67%|

Figure 12. Shrinkage curve of mortar with different curing time.

Figure 13. Fitting curve of age x and shrinkage rate y under 40% humidity curing condition.

Figure 14. Fitting curve of age x and shrinkage rate y under 75% humidity curing condition.

Figure 15. Fitting curve of age x and shrinkage rate y under 90% humidity curing condition.
3. Time influence analysis: The curing time of acrylic emulsion mortar is mainly concentrated in the 1 to 3 days of curing before drying. Therefore, early curing measures must be taken for acrylic emulsion mortar to effectively control the early shrinkage cracks of the mortar.

4. Humidity influence analysis: When the acrylic mortar is dried, the curing humidity has the greatest influence on the cracking of the acrylic mortar. As the curing humidity increases during drying, the drying shrinkage rate is significantly reduced. The drying shrinkage rate drops to a minimum on the 7th day, reaching the 40%, and after 35 days it decreases to 62%. The effect of curing humidity on drying shrinkage during drying is greater in the early period of the curing period, and gradually smaller in the later period. When the curing humidity is above 90%, the shrinkage is the smallest. During the construction process, the curing humidity during drying should be kept above 75%.

6. Benefit analysis

6.1. Economic benefit
Through unit price analysis, the unit price of traditional acrylate mortar surface protection is 199.68 yuan/m² (double acrylate mortar). According to the research results of the key technology of anti-cracking of acrylic emulsion mortar in this project, by optimizing the proportion of acrylic emulsion mortar and selecting specific conditions for construction and maintenance, and repairing the concrete carbonization and erosion surface, it can reduce the drying shrinkage rate of the acrylic emulsion mortar and improve the cracking situation. The unit price of the improved acrylic emulsion mortar is 154.68 yuan/m². The unit price saving rate is 22.54%[(199.68-154.68) × 100% /199.68] or more.

6.2. Social benefit
The research results of this project provide a lot of reference data and basis for the construction of acrylic emulsion mortar surface protection in the future. The improved construction technology and quality control measures are guiding for the construction of acrylic mortar in the future. More importantly, the cracking phenomenon of acrylic emulsion mortar surface protection has been effectively solved. While reducing the cost, it has improved the flood control strength of the culvert and sluice and prolonged the overall service life of the culvert and sluice. Therefore, the social benefits of the key technology of anti-cracking of acrylic emulsion mortar are outstanding and obvious in the reinforcement of culverts and sluices.

7. Conclusion
1. This project mainly solves the problem that acrylic emulsion mortar is easy to produce cracks in the culvert and gate reinforcement project.
2. The results of this research have found the key factors affecting the cracking of acrylic mortar during construction. The shrinkage performance under standard curing conditions was compared with that under natural conditions, and the shrinkage performance of acrylic emulsion mortar in the repair and reinforcement of culvert and sluice was tested and analyzed.
3. Through repeated periodic tests, after extracting the data of the standard curing environment and natural environment, the drying shrinkage rate was calculated, and the data was extracted by polynomial fitting method, and the limit of construction (and curing) temperature, humidity and time of acrylic emulsion mortar were obtained.
4. According to professional laboratory tests and on-site application in the Dongchi sluice, the key technology of anti-cracking of acrylic emulsion mortar has achieved economic benefits while also achieving social benefits. In the future, the key technology of anti-cracking of acrylic emulsion mortar will be applied in the culvert sluice reinforcement project in the Yellow River Basin. The promotion and application prospects of key technologies are very broad.

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