Influencing factors and experimental study on performance of composite cement-based grouting

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Abstract: The performance of grouting material directly affects the grouting effect under cement concrete pavement slab. In this paper, the factors affecting the fluidity, strength and bleeding rate of grouting materials are analysed by repeated tests. The test results show that the slurry with good suspension is not easy to be diluted by water and has certain waterproof performance; The water-cement ratio is in the range of 0.35 to 0.5, and the suspension is good and not easily separated; Incorporation of fly ash will cause early strength reduction and increase of slurry bleeding. It is recommended not to exceed 50% of cement. Finally, it is suggested that the strength of the grout should not be as high as possible, and the problem of strength development at the late stage of grouting and matching of the strength of the base layer should be fully considered.

1. Introduction
With the extension of service life, cement concrete pavement appeared different degree of disease, such as Pumping mud, faults, cracks, broken slab, etc., the occurrence of these diseases are more or less closely related to plate bottom emptying. At present, the grouting technology is one of the most effective and economical measures to solve the problem of plate bottom emptying. In order to reduce the voiding damage of cement concrete pavement slabs, the cement pavement maintenance specifications require that the slabs should be grouted immediately after the voids appear.

The grouting stabilized plate technology has been used as a preventive maintenance measure. China and other countries in the world generally adopt the grouting technology to deal with emptying. However, lot of engineer practices demonstrate the grout under slab technology is not so easy to control. The grouting effect of the cement concrete pavement not ideal, and some pavement damage is accelerated after grouting. One of the reasons is that the performance of the grout is not satisfactory. Grouting technology has high requirements on the comprehensive performance of materials. The grouting material with excellent performance can really strengthen, repair and prolong the service life of the concrete pavement. Otherwise, the pavement performance will be further reduced.

Grouting materials for cement concrete pavement are mainly cement slurry, cement fly ash slurry, cement mortar and asphalt perfusion for under-board plugging. Li Zihua applied cement slurry,
expansion agent, fly ash, etc. for grouting treatment, and achieved good results. Zhou Zhijian\cite{5} used cement mortar to grout the concrete slab. It was found that the sand can effectively reduce the shrinkage of the slurry, and at the same time save the amount of cement, but the proportion increases the bleeding of the slurry. Li Ye and Gao Wei\cite{6} studied the process of adding emulsified asphalt and chopped polypropylene fiber to the bottom of the cement slurry to improve the compressive/folding ratio and flexibility of the grouting material.

In this paper, the factors that concern suspension, fluidity, strength, expansion rate and bleeding performance of grouting materials were discussed, and a reasonable index range was given. It is further proposed that the strength properties of grouting materials should take into full consideration their compatibility with the existing base strength.

2. Test

2.1. raw materials
The cement used in the test is Portland cement P.O42.5, the mechanical properties of the cement are shown in Table 1; Grade I fly comes from a power plant, its specific surface area of fly ash is 450m2/kg; The natural sand contains less than 1% mud and we just need fine sand below 0.6mm pore size; Other admixtures include high-efficiency water reducing agent, pumping agent, early strength agent, expansion agent, and air entraining agent: Engineering water.

| Type of cement | Fineness (%) | Setting time (min) | Stability | Flexural Strength (MPa) | Compressive Strength (MPa) |
|----------------|--------------|--------------------|----------|------------------------|--------------------------|
|                | (0.08mm)     | Initial            | Final    | 3d                     | 28d                      |
| P.O42.5        | 1.78         | 147                | 217      | qualified              | 4.8                      |
| GB 175-2007    | 10           | ≥45min             | ≤600min  | qualified              | ≥3.5/6.5/17.0/42.5       |

2.2 Test methods

2.2.1. strength
According to the test method T0506-2005 test method of cement mortar strength in JTG E30, the standard of transportation industry, the size of the specimen is 4cm×4cm×16cm, and non-vibration molding is adopted.

2.2.2. Vertical fluidity
According to the test method T0508-1 cement slurry flow measurement method in JTG E30. During the test, the prepared slurry was poured into the inverted cone. The volume of the inverted cone was 1725 ml ± 5 ml. The time required for the entire slurry to pass through the cone was measured as vertical fluidity (at room temperature, the time pure water flowed out is 8s).

2.2.3. Horizontal spread
The test shall be carried out in accordance with Appendix A of technical code for application of concrete admixtures (GB 50119-2003) for which the truncated cone is round die dimensions: height (60 ± 0.5) mm; inner diameter of the upper opening (70 ± 0.5) mm; an inner diameter of the mouth
(100±0.5)mm; the outer diameter of the lower mouth is 120mm.

2.2.4. Expansion
The test of cement slurry expansion is carried out using self-developed equipment. As shown in Figure 1.

![Figure 1. Cement (sand) slurry expansion rate test device](image)

Note:
1 Dial indicator;
2 Test cover;
3 Transparent plexiglass cylinder test mode;
4 Flange;
5 Cylindrical test base;
6 Support;
7 Level bubble;
8 Leveling screw.

2.2.5. Bleeding
The test shall be carried out in accordance with Appendix C4 of Technical Specifications for Construction of Highway Bridges and Culverts (JTG/T F50-2011).

3. Test plan
The mix ratio of grouting material under cement road slab is different from that of concrete material. There is no mature design calculation formula, and it can only be repeatedly tested according to the experience of grouting. The preliminary selection of water-to-binder ratio is between 0.35 and 0.45, the amount of water reducing agent is 0.7% to 1.0%, the amount of pumping agent is 0.5% to 1.0%, and the expansion agent is selected to be 8% to 12%.

4. Results and discussion

4.1. Test results and analysis

4.1.1. Liquidity
The vertical fluidity (s) and horizontal spread (mm) are generally used to comprehensively evaluate the fluidity of the grouting material.

The test results show that the pumping agent can increase the vertical fluidity of the mortar, and the high-efficiency water reducing agent can increase the horizontal spread.

Through further tests, when the vertical fluidity is between 14s and 23s (as is shown in Fig. 2), the workability of the slurry is better, the suspension is good, and the segregation is not separated. When the fluidity is less than 14s, the slurry is relatively thin and easy to be separated. The slurry above 23s is thicker, although it is not easy to isolate, but the horizontal fluidity becomes smaller. Therefore, it is preferable to control the vertical fluidity in the range of 14s to 24s, and the horizontal spread is generally
370 to 390 mm (as is shown in Fig. 3).

**Figure 2.** Vertical fluidity of grout

**Figure 3.** Horizontal spread of grout

### 4.1.2. Bleeding

1. **Water-to-binder ratio**

   The water-to-binder ratio is large, and the flowability of the slurry is good, but the slurry is easily separated and the bleeding rate is also increased, which affects the strength of the slurry. For the sand-free grouting slurry, the water-to-binder ratio can be controlled from 0.35 to 0.45, and the mortar can be increased increased to 0.6. The final result is based on engineering trials.

2. **Sand effect**

   The addition of fine sand can increase the strength of the grout, reduce the shrinkage performance of the slurry, and at the same time reduce the amount of cement and other cementing materials, thereby reducing the engineering cost of the grouting plate, but the large-size sand is prone to segregation and bleeding. Therefore, we use fine sand. Of course, the fineness modulus of sand and the amount of sand are related to the situation of voiding. The finer the sand, the higher the amount can be. The larger the amount of voiding of the plate, the larger the amount of sand can be correspondingly larger, according to the construction site. The specific situation to determine the program.
The amount of sand is closely related to the fluidity, expansion property, bleeding property and strength of the slurry. For the grouting material with fine sand, the bleeding of the grouting material is increased, because the fine sand must meet the requirements of the fluidity, and the water must be increased. However, only the hydration reaction of the cement is needed. Adding fine sand grout, the water-to-gel ratio is about 0.4~0.59. The amount of fine sand must be tested to achieve the best ratio of cement particles, fly ash particles and sand particles in the cement slurry. According to the observation and test results in the test, the ratio of sand/cement = 0.7~1.2 is used, the bleeding rate of the slurry is small, and it is close to no water at 24h.

(3) Influence of fly ash

The addition of fly ash can reduce the amount of cement, save costs, improve the workability and shrinkage of the slurry, and facilitate the development of long-term strength. However, it was found in the experiment that the addition of fly ash not only reduces the early strength of the slurry, but also causes the slurry to produce bleeding, especially when it exceeds 50%, it is prone to bleeding. In the test, it was concluded that considering the various factors, the amount of fly ash is recommended to be less than 50% of the cement.

4.1.3 Suspension

Good suspension cement base composite grouting material is the premise of low bleeding rate and good strength performance. We further tested the grout with good fluidity and no segregation during the above test preparation process: leave a small amount of water at the bottom of a large basin, and inject the grout into the pot and find that the slurry can be used at the bottom of the basin. The water is pushed away and suspended in the surface layer of the slurry, and the slurry itself is not easily diluted by water and has waterproof properties. Imagine that if the actual pavement grouting, the well-suspended grout can discharge the water at the bottom of the board out of the cement road panel under a certain pressure, thus playing the role of grouting stability.

4.1.4 Strength

(1) Impact of bleeding

It is preferred to carry out a strength test in a test ratio in which the slurry has good suspension property, large fluidity, and less bleeding after 24 hours. The test results show that the bleeding rate has a great influence on the strength. As shown in Fig. 5, the strength of the slurry with bleeding after 24 hours is significantly lower than that of the non-bleeding slurry.

It can be seen from Fig. 4 that the strength of 2# slurry is the highest, the quality of the slurry is good, the slurry has no segregation, and the suspension is good, and there is almost no bleeding at 24 hours. 1# and 3# have a high rate of bleeding, and their early and late compressive and flexural strengths are lower, 4# less water, and the strength is centered.
Figure 4  Effect of bleeding on strength

(2) Impact of expansion

The dosage of UEA in this test is 10%~15%. It can be seen from Fig. 5 that the effect of expansion ratio on the intensity is inversely proportional to the early 1d to 7d. The slurry with a small early expansion rate has a higher growth rate in the later stage. For example, the early expansion rate of the 16# slurry is 4.4%, but the growth rate of the late strength is the lowest. The early expansion rate of the 20# slurry is 0.2%, but the growth rate of the late strength is the highest. It can be seen that the expansion rate of the grouting material is too large to cause a decrease in strength in the later stage.

Figure 5  Expansion effect on the strength

4.2. Grout strength and base strength matching

For bottom grouting materials, the coordination of the strength of the grouting material with the strength of the substrate is critical. Grouting treatment technology is mainly to restore the uniform support conditions of the base layer under the panel. If the strength of the grouting material is much greater than the strength of the base layer, it will cause uneven support of the bottom of the board, which will lead to further damage of the panel.
5. Conclusion

(1) The pumping agent can increase the vertical fluidity of the mortar, and the high-efficiency water reducing agent can increase the horizontal spread. When the vertical fluidity is 14s~24s and the horizontal spread is generally 370~390mm, the composite slurry has good suspension, no segregation and stratification, and close to no bleeding after 24h. The slurry with good suspension is not easily diluted by water and has certain waterproof performance;

(2) The water-to-binder ratio directly affects the fluidity of the slurry, but the performance of the slurry should be fully considered to control the water-to-binder ratio of 0.35~0.45 (without sand), and the water-cement ratio can be appropriately increased for the sanded grout.

(3) The amount of sand is closely related to the fluidity, swelling property, bleeding property and strength of the slurry. It is recommended to use sand/cement = 0.7~1.2 ratio.

(4) Fly ash has a certain effect on the fluidity of the grout, but it is unfavorable to the early strength, and will also increase the rate of bleeding of the slurry. Therefore, it is recommended that the amount of fly ash is less than 50% of the mass of the cement.

(5) The strength of the grout should be matched with the strength of the base layer. When the strength of the grouting material is much greater than the strength of the base layer, it will cause uneven support of the bottom of the plate, which will lead to further damage of the panel.

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