Study on the properties of composite mineral admixture material for rapid repair

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Abstract: In this paper, the active mineral admixture was used to prepare the quick repair material that meets the requirements of 24h service. The development of the late strength, the shrinkage performance and wear resistance of the 60days were studied. The experimental results show that the composite mineral admixture is used to prepare the material for rapid repair, not only the early strength is high, but also the later strength is steadily increasing, and the dry age of 60 days is reduced, and the wear resistance is good. The use of industrial waste has certain economic and social benefits.

1. Introduction
With the rapid increasing of concrete pavement in China, also the prolong of road service period. The road fast repair become an important and usual work. Also because of the increasing traffic volume and accelerated economic pressure, the road repair is always very urgent. But for the properties of cement concrete, the strength always comes 14 to 20 days after the repair. The maintenance and repair process needs to block roads for a long time, which has seriously affected the normal operation of vehicles and caused frequent traffic jams. At the same time, it also leaves hidden dangers for traffic safety [1]. A save and quick material for road repair is essential for the maintenance technology of cement concrete pavement.

Cement concrete pavement repair materials are divided into inorganic, organic, composite of organic and inorganic. Organic repair materials mainly have epoxy resin, polyurethane, its advantages are good corrosion resistance, good bonding, but brittle expensive. Organic and inorganic combined repair materials are mainly polymer modified mortar or concrete [2], its characteristics are shrinking, strength bonding performance is good, but the price is expensive, and it is not suitable for large areas of repair. Therefore, its promotion and application are limited. Inorganic repair materials are more common and use special cement [3]–[5] such as fast hard sulfur-aluminate cement, high-aluminum cement, magnesium phosphate cement, etc. There are also repair materials formulated with complex chemical admixtures or with active mineral blends. There is information that some of the fast repair materials modified by special cement have higher early strength, but in the later period, there will be strength retraction, reduced wear resistance, and poor bonding ability between old and new concrete [6]. The study of early strength concrete relying only on chemical additives has certain defects, even if the early strength performance can be met, and the stability of the later strength growth and its durability is difficult to guarantee.

Considering the condition of the repair material, the use of compound admixture and mineral admixture is one of the ideal solutions. Therefore, this paper makes full use of mineral admixture and chemical admixture, optimizes the ratio with strength as the goal, puts forward the ratio of fast pass
concrete that meets the requirements of 24-hours traffic, and further studies the development trend of strength performance of fast repair materials, dry shrinkage, wear resistance. Through the research, using the industrial slag, the rapid repair material of cement concrete has developed rapidly in the early stage, stable in the later stage, and has small deformation, high wear resistance and good construction performance. At the same time, it saves cement, protects the environment, and has significant economic and social benefits.

2. Test raw materials and match ratio

2.1. raw materials
The cement used in the test is road Portland cement P.R7.5. The mechanical properties of the cement are shown in Table 1. The fine aggregate used is medium sand with a fine modulus of 2.5; The coarse aggregates is continuously distributed from 5mm to 31.5 mm, with a mud content of no more than 0.2 %; The admixture is Class I fly ash and silica ash; The chemical admixture is sulfate early strength agent, naphthalene series highly effective water reducer.

Table 1 Test results of physical and mechanical properties of road Portland cement

| Type of cement | Fineness (%) | Setting time (min) | Stability | Flexural Strength (MPa) | Compressive strength (MPa) |
|----------------|--------------|--------------------|-----------|------------------------|---------------------------|
|                | (0.08mm)     | Initial            | Final     | 3d                     | 28d                       |
| P.R7.5         | 2.78         | 140                | 215       | qualified              | 5.23                      |
|                |              |                    |           | 8.00                   | 22.0                      |
|                |              |                    |           | 43.0                   |                           |

2.2. matching ratio
By optimizing the ratio, the strength test results for each age are as below (table2):

Table 2 Test results on strength of rapidly repaired concrete materials

| technical index number | Admixture ratio(%) | strength of concrete (MPa) |
|------------------------|--------------------|---------------------------|
|                        | Fly ash/ Silicone  | Bend / Compressive        |
|                        |                    | 1d  2d  3d  7d  28d  60d |
| J1                     | 0/0                | 2.90/19.0 3.20/22.0 4.50/25.0 7.35/34.8 8.60/40.0 8.50/48.4 |
| JS1                    | 0/6                | 5.00/26.3 6.49/35.8 7.15/42.3 7.51/49.9 9.30/58.8 11.60/58.9 |
| JF1                    | 5/0                | 3.35/21.0 5.53/29.9 6.70/36.1 8.20/47.7 10.80/51.1 11.60/63.2 |
| JF2                    | 10/0               | 2.87/19.6 5.29/28.0 6.04/32.5 7.80/42.4 10.90/45.9 10.70/51.5 |
| JF3                    | 15/0               | 2.77/18.2 4.11/28.2 5.00/32.3 7.20/42.4 10.60/47.1 8.60/50.0 |
| JFN1                   | 5/0                | 4.20/25.3 5.80/31.3 6.40/37.8 7.20/44.2 8.70/47.2 10.50/53.1 |
| JFN2                   | 10/0               | 3.87/18.2 5.11/29.0 5.00/32.3 7.28/42.4 10.40/47.8 8.60/50.0 |
| JFS                    | 5/6                | 4.27/21.9 6.20/37.0 7.40/37.4 7.80/47.7 10.40/58.9 11.40/63.9 |

3. Analysis and discussion of results

3.1. Development of strength (60 days)
For the rapid repair of concrete materials, the early strength is important, but the later strength should not decay quickly, otherwise it will affect the repair effect. At present, many repair materials are used poorly due to the serious retraction of the later strength, and the second damage. In this paper, the strength development of the later 60 days is studied, and the effect on strength is further analyzed. The compressive strength and bending strength development of 1 day to 60 days are shown in Figure 1 and Figure 2 respectively.
As it shows in Figure 1 and Figure 2, the early strength of the reference concrete (J1) developed slowly. 3 days to 28 days is the principal strength development period. After 28 days, the bending strength does not develop. Compressive strength develops slowly.

Silica concrete (JS1), 1 day to 3 days bending strength develops rapidly, 3 days to 7 days strength develops relatively slowly, and the bending strength of 7 days to 60 days increases significantly, accounting for about 38% of the total bending strength. It shows that the micro-particles of silica fume are much smaller than the micro-particles of cement. After replacing some cement with silica fume, it can be well filled between cement particles, improving the particle gradation of cementitious materials, and exhibiting high early strength.

The reaction of silica ash with the ash of Ca(OH)₂ effectively fills the capillary structure of the cement slurry, improves the microstructure of "cement stone" formed after cement, reduces the porosity of the concrete, and increases the strength of the concrete hardening period.

The strength development curve of fly ash concrete JF1 shows that although the 1day bending strength is not high, the later 28 days to 60 days bending strength reaches 10.8MPa to 11.60MPa. It is equivalent to the post-bending strength of silicon-doped concrete. The compressive strength of JF1 concrete after 28 days performed well, and its 60 days compressive strength reached 63.2MPa, an increase of 7.3% over JS1. The early strength of fly ash JFN1 concrete added to the early strength agent was 2.5% higher than that of JF1, but the strength of the later 60 days was 19.2% lower than that of JF1, indicating that the addition of early strength agent was unfavorable to the growth of the later strength. JF2, JF3 With the increase of fly ash admixture, the intensity development is gradually lower.

According to the data analysis in Table 3, concrete with 5% early strength agent(JFN1) added to
fly ash concrete has a compressive strength of 20.4 % higher than that of fly ash concrete(JF1), but the strength of the later 60days is 15.8 % lower. The compressive strength of fly ash concrete 60days with 10 % early strength agent(JFN2) was reduced by 20.8 %.For the flexural strength, JFN1 and JFN2 increased by 23.8% and 15.5%, respectively, compared with the 1day age of JF1. However, the flexural strength of 60days was reduced by 9.5% and 25.8% respectively. It shows that although the addition of early strength agent can increase the early strength, it is unfavorable or even greatly reduced for the increase of late strength.

The strength of the complex fly ash and silica ash concrete(JFS)in the early 1day was greater than that of JF1, smaller than the 1d strength of JS1. However, the compressive strength of 60 days reached a maximum of 63.9MPa, which was higher than that of JS1and JF1. The results show that Silica powder and fly ash each exert their own advantages and produce compound superposition effect.

The above strength results indicate: The addition of silica ash and fly ash to concrete not only increases the early strength of concrete, but also ensures the stable increase of the late strength of concrete. The micro-silicon powder particles are small and equal to the amount of cement particles. In the early stages, the hydration reaction of cement is promoted, and it is filled in the pores of cement stone to form a dense matrix structure with low porosity. Therefore, micro silicon powder has a significant early strong effect. Although fly ash has no interest in early strength, due to the micro aggregate effect of coal ash and the secondary hydration reaction with cement, the microstructure of concrete can be changed, the density of concrete can be increased, and the durability of concrete can be improved. In terms of mechanical properties, it is shown to enhance the late strength of concrete. Therefore, the addition of appropriate amount is very beneficial to the stability of concrete materials and the increase of late strength.

3.2. Dry shrinkage performance
Dry shrinkage of repair materials is one of the important factors that affect the performance of quick repair concrete. In the repaired concrete, the drying shrinkage of the old concrete has been basically stable, and the drying shrinkage of the newly poured repairing material has just begun to occur. At the interface between the old and new concrete, shrinkage under the constraints of the old concrete will cause cracking of the concrete, resulting in durability of the concrete bad effects.

Large amount of data indicate that ultra-fine fly ash can better inhibit the shrinkage of concrete due to its excellent water-reducing performance, dense filling and micro-aggregate effect. In this test, it can be confirmed from Figure 3 that the dry shrinkage deformation of fly ash concrete decreases with the increase of the amount of fly ash, that is, JF3<JF2<JF1, as shown in Figure 3. The amount of fly ash is 5% for JF1、 10% for JF2 and 15% for JF3. The concrete shrinkage of concrete-doped silica fume JS3 is the largest, followed by JS2 and JS1. It can be seen that the increase of silica fume content is very unfavorable for dry shrinkage, as shown in Figure 4. It has been found that the addition of early strength agent will also lead to an increase in the shrinkage deformation of concrete, and the strength of the later stage will also shrink.
3.3. Wear resistance
Wear resistance is an important performance of highway cement concrete pavement. Under the influence of increasing traffic load, cement concrete pavement produces severe wear diseases such as peeling, pockmark and exposed bone, which seriously affects quality cement concrete pavement. Therefore, cement concrete repair materials must also have good wear resistance. The test results show that the best wear resistance is found in the repair material with silica. The test results are shown in Table 3 below:

| Specimen | JCNI-1 | JCS-1 | JCF-1 | JCFNI-1 |
|----------|--------|-------|-------|---------|
| Abrasion (kg/m²) | 0.520 | 0.510 | 1.04  | 1.16    |

4. conclusion

4.1. To meet the requirements of 24h open to traffic, composite concrete with JC, JCS-1, and JCFN1 ratios is recommended. The content of Silicon powder is 6% of cement. The recommended amount of fly ash instead of equivalent cement is 5% to 10%. The early strength agent and the high efficiency water reducing agent are determined by the indoor test and the coordination ratio design target. Additives should be selected taking into account the adaptability of cement.

4.2. The test results indicate that the dry shrinkage deformation of fly ash mixed with concrete is small, the early strength agent and silica ash are not conducive to the dry shrinkage of concrete materials, and the amount of silica ash mixed is not recommended to exceed 10%.

4.3. The wear resistance of the material after the optimized ratio meets the wear resistance requirements of the concrete pavement, which is between 0.5 kg/m² and 1.16 kg/m², of which the concrete material with Silicon ash has the best wear resistance.

4.4. The experimental study of rapid repair materials make full use of microsilicon powder and local industrial waste fly ash, which has not only effectively increased the early strength of Fastcom concrete, but also ensured the stable growth of the later strength of concrete. It is also beneficial to the drying deformation and wear resistance of concrete. The rapid repair materials studied in this experiment have made full use of local resources, saved the cost of raw materials, protected the environment, and achieved great economic and social benefits.

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