Performance Research on Rapid Repair Materials of Composite Cementitious Materials

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Abstract: In order to repair construction rapidly, according to the different proportion, ordinary Portland cement and sulphur aluminate cement (SAC) are used to make up composite cementitious materials, the setting time, strength and deformation of composite system are researched to satisfy the special requirement of fast repair. Test results show that composite cementitious materials have superior performance in various aspects when the SAC is 15%, on the basis of this benchmark ratio mixed with proper amount of polypropylene fiber, high efficiency water reducing agent and mineral admixtures, composite cementitious mortar can be made out with a short setting time, good workability and high strength.

1. Introduction
Repair materials include organic and inorganic materials, at present, the research mainly focuses on traditional epoxy resin mortar or resin concrete, but high polymer materials have higher requirements on material compatibility, and the damage phenomenon of aging and cracking of organics in later stage can greatly reduce the performance of repair materials, in addition, the preparation is complex and the cost is high. Therefore, inorganic repair materials are superior to organic repair materials in durability, strength, compatibility and cost.

K.E. Hassan, et al. [1] pointed out that repair mortar with ordinary ordinary Portland cement had a similar elastic modulus with the old concrete, which made them good compatibility. However, its shrinkage rate was large, which had adverse effects on compatibility. In addition, the curing period of ordinary Portland cement was also long, which extended the repair period and was not suitable for emergency repair engineering. Koich Kobayashi, et al. [2] studied the corrosion resistance of fiber reinforced cement-based patching materials, and found that polyethylene fiber could effectively prevent steel corrosion and improve workability with low dosage. Cabrera, et al. [3] considered that the impermeability and pore structure were the most reasonable indexes to evaluate the performance of repairing mortar.

In the field of cement-based repair materials, in recent years, some Chinese colleges and scientific research institutions have also studied the repair material and repair technology. For example, Bingxi Zhu [4] of Jiangsu province successfully developed a high-performance repair ME - 4 mortar, high performance repairing materials was made out by silica fume, fly ash, slag powder and PPF fiber, it had good workability, good water retention, adhesiveness, fast hardening. A rapid repair concrete [5] developed by Hunan university had slightly expanding and crack resistance, it appeared obviously better than that of ordinary concrete. But these repair materials also had various deficiencies, such as high cost, late strength shrinkage, fast condensation and difficult workability.
In order to solve these problems, in this paper, ordinary Portland cement and Sulphate aluminate cement are combined in different proportions, on the basis of the determined benchmark mix ratio, materials such as anti-cracking fiber, superfine mineral admixture and water reducing agent are added to meet rapid repair requirements.

2. Experimental

2.1 Materials

In this test, ordinary Portland cement with 42.5 level is produced by conch cement factory (Nanjing, Jiangsu, China), Sulphate aluminate cement (SAC) with 42.5 level and low alkali is produced by Tangshan cement plant (Tangshan, Hebei, China). Polypropylene fiber is used for reinforcement and crack resistance, fiber's density is about 0.90~0.92 g/cm³ and length is about 10 mm, it is produced by Nanjing new material co., LTD (Nanjing, Jiangsu, China). Water reducing agent is superplasticizer of polycarboxylic acid (PCA VII), it is produced by Nanjing new material co., LTD. In this test, two mineral admixtures are slag powder and silica fume. The mineral admixtures are superfine powder, their average particle size is 0.1~0.5 micron and the SiO₂ content of silica fume and slag powder are 98% and 43% respectively.

2.2 Test methods

Setting time: according to JGJ/T 70-2009 《test method of setting time for cement mortar》 (China), the penetration resistance method is adopted to determine the setting time of mortar mixture.

Deformation performance: according to JGJ/T 70-2009 《test method of dry shrinkage for cement mortar》 (China), dry shrinkage test is conducted for repairing mortar. Vertical mortar shrinkage meter (micrometer) is used for testing. The size of specimen is 40 mm × 40 mm × 160 mm.

Strength: according to GB/T 17671-1999 《test method of strength for cement mortar》 (ISO), the size of specimen is 40 mm × 40 mm × 160 mm.

Fluidity: according to GBT2419 《test method of fluidity for cement mortar》 (China), “Jump table” test is adopted to repair the fluidity of mortar and assess its fluidity.

3. Results and Discussions

3.1 Performance test of composite cementing system with ordinary Portland cement and sulphur aluminate cement (SAC)

Generally, different types of cement cannot be mixed. In order to display the advantages of two different kinds of cement at the same time, two kinds of cement are mixed proportionally to obtain various requirements of rapid repair materials.

After adding a certain amount of SAC into ordinary Portland cement, the phenomenon of early coagulation and strength appear, because the SAC consumes the concentration of Ca(OH)₂, reduces the alkalinity of cement paste, accelerates the hydration of calcium silicate in ordinary Portland cement, and speeds up the hydration speed. At the same time, the anhydrous calcium sulphaaluminate in SAC reacts with gypsum to form ettringite (AFT) quickly, which results condensation rapidly, so the early strength of cement mortar is greatly improved, but the fluidity of slurry decreases.

3.1.1 Setting time

In composite cementing system with ordinary Portland cement and Sulphate aluminate cement, the binding material-sand ratio is 1:2, the water-cement ratio (W/C) is 0.5, and the content of Sulphate aluminate cement in the composite system is 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50% respectively. In order to achieve the requirements of rapid solidification and early strength of repair materials, the setting time of mortar is measured without using admixture in order to determine the optimal amount of SAC.
The test results show that the setting time of composite cementitious materials decreases with the increase of SAC content. In this complex system, silicate minerals is the main ingredient, but SAC plays a main role for early hydration, the anhydrous calcium sulfoaluminate in SAC produces chemical reaction rapidly with gypsum and forms ettringite, thus the early strength of cement mortar is greatly improved. When the amount of SAC is between 15 and 30 percent, the setting time of the composite cement system is basically about 80 minutes, which can fully meet the requirements of quick repairing and construction.

3.1.2 Strength
In composite cementing system, the binding material -sand ratio is 1:2, the water-cement ratio (W/C) is 0.5, and the content of SAC in the composite system is 5%, 10%, 15%, 20%, 25%, 30%, respectively. The strength of mortar is measured in order to determine the optimal amount of SAC.

Fig.1 and Fig.2 show that two kinds of strength change with increase of SAC. When the content of SAC is between 0 and 15%, the flexural strength and compressive strength of the composite system of 3 days and 28 days appear growth, when content is 15%, it reaches the peak value. At this time, the growth rate of flexural strength and compressive strength of 3 days are 53.76% and 53% respectively, and that of 28 days are respectively 39.87% and 22.01%, so the optimal content of SAC in the composite system is preliminarily determined to be 15%.

3.1.3 Deformation performance
Good deformation performance is the primary requirement for repair materials. Therefore, in order to verify and analyze the deformation performance of the composite cementing system, 10%, 20% and 30% of the content of SAC are used respectively.

Table 1 Deformation test results of mortar specimens

| age (d) | SAC content / % | 10 | 20 | 30 |
|---------|----------------|----|----|----|
| 7d average deformation / mm | 0.1714 | 0.0908 | 0.0319 |

Table 1 shows that the shrinkage deformation of cement mortar specimens decrease gradually with the increase of SAC. When SAC meets water, it rapidly produces AFT, and during this process, 2~2.5 times volume expansion appears, because SAC plays a role of micro expansion.

3.2 Modification of polypropylene fiber
When the optimum content of SAC is 15% in the composite system, the volume change and strength of cement mortar specimen are analyzed with polypropylene fiber.

| age (d) | Fiber content / % (volume content) |
|---------|-----------------------------------|
| 0       | 0.1                               |
| 0.1     | 0.15                              |
| 0.15    | 0.2                               |

Table 2 Deformation test results of mortar specimens
Table 2 shows that shrinkage deformation of specimen decreases after adding polypropylene fiber, these specimens have base blending ratio with 15% SAC. The shrinkage deformation of the specimen decreases continuously with the increase of fiber volume dosage. Under stress, fiber will play a positive role in preventing cracks, and greatly reduce the shrinkage deformation, so it can reduce the repairing cracks of mortar in the process of hardening.

![Fig.3 Strength of mortar specimens with different fiber content](image)

Fig.3 shows that flexural strength and compressive strength improve after adding polypropylene fiber, especially the flexural strength is more obviously. When the fiber content increases from 0 to 0.2%, the 3-day flexural strength growth rate is 23.0%, 27.8% and 31.8%, respectively. The 28-day flexural strength growth rate is 38.0%, 44.8% and 49.8% respectively. It can be seen that fiber greatly increases the flexural strength of specimen, the compressive strength increases smaller at the same time.

3.3 Modification of water reducing agent

Water reducing agent PCA (Ⅶ) is used on the base of benchmark ratio, water/cement ratio is changed by 0.5, 0.4, 0.3 and 0.2 respectively.

Test shows that the fluidity of composite cement mortar decreases significantly with the reduction of W/B under the condition of using water reducing agent. When W/B is more than 0.35, the fluidity of mortar basically meets the requirements of construction work. Fig.6 shows that the 3d flexural strength and compressive strength of specimen are 6.23MPa and 29.82MPa respectively when W/B is equal to 0.35, and the folding strength and compressive strength of the composite cement mortar increase 12.75% and 9% respectively than benchmark mixing ratio.

3.4 Modification of mineral admixture

The fluidity and strength of cement mortar are tested by adding slag powder and silica ash on the base of benchmark mixing ratio.

The fluidity of the composite cementitious materials decreases significantly after adding silica fume. When the content is less than 10%, The fluidity of composite cementitious materials is improved after adding slag, which is convenient for construction and repairing.

. Fig4 shows that flexural strength and compressive strength are higher when the content of silica fume is 10%. In particular, early and late flexural strength are higher, so the optimum content of silica fume is determined to be 10% preliminarily. This is because the silicon ash powder does not play activity in early time, it only plays basic material effect, namely powder filling effect which can improve the compactness of set cement and increase the compressive strength. With cement continue hydration, the activity of mineral powders constantly plays, a large amount of active silicon dioxide(SiO2), reacts with calcium hydroxide( Ca(OH)$_2$), new silicate with higher strength is produced. Therefore, the later strength increases obviously.
4. Conclusions

In composite cementitious system with ordinary Portland cement and Sulphate aluminate cement (SAC), fiber, mineral admixture and water reducing agent are added respectively to achieve an optimal ratio, experimental results show that the properties of composite cementitious materials can meet the requirements of rapid repair materials on setting time, deformation performance, strength and workability. The following conclusions are obtained from the test results:

(1) In composite cementitious system, the optimal ratio of SAC is 15%. Composite cementitious mortar for rapid repair can be made out, this repair mortar has many advantages such as shorter hardening time, good construction, high early strength and late strength.

(2) The repair mortar mixed with polypropylene fiber not only has faster condensation rate, but also higher flexural strength and compressive strength.

(3) A moderate amount of silica fume and slag power can, to some extent, improve strength of composite cementitious mortar on later stage, especially the compressive strength. The mixed slag can improve the liquidity, but greatly reduces the early strength. The mixed silicon ash can improve early strength less, therefore, suitable admixtures can be added to improve the liquidity conditions.

The analysis of the above test data shows that the optimum content of silica fume is 10%. If the silica ash and slag are mixed in proportion into composite cementitious system, both advantages can be brought into at the same time. To some extent, mineral admixture can not only improve the workability, but also greatly improve the early and late strength of the composite cementitious mortar, which can meet the requirements for quick repair.

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