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*Full Length Research Paper*

# Experimental research on high-fluidity and super high-early strength concrete for cement pavement repairing

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**The concrete used for pavement repair must have a very high-early strength for opening to traffic, good anti-shrinkage and anti-cracking performance, and interfacial bond between old and new concrete surface, besides the basic pavement performance. High fluidity is also needed for simplifying repairing operation and for guaranteeing the repair quality. In a sense, high fluidity is conflict with super high-early strength. In this paper, focusing on the early flexural strength, interfacial bond, shrinkage and cracking performance, the preparing and testing of high-fluidity and super high-early strength concrete (HFESC) for pavement repair was investigated. The repair concrete material, which is prepared with rapid hardening sulphoaluminate cement, aminobenzene sulfonamide superplasticizer and RF admixture, has 3.5 MPa 5 h-flexural strength, 20 MPa 5 h-compressive strength and 200 mm slump value. The laboratory test and field pavement repairing results revealed that the concrete has high fluidity and good mechanics performance and durability, which can be used in rapid repair of concrete pavement.**

**Key words:** Rapid repair, superplasticizer, compatibility, early-strength admixtures, interfacial bond strength.

## INTRODUCTION

Cement concrete pavement (CCP in short) is possessed of traffic safety, stability and durability comparing with asphalt pavement. Besides which, the comprehensive cost especially maintenance expense of CCP is lower than that of asphalt pavement. While the rehabilitation of pavement surface distress, once it occurs, must be conducted in time for avoiding the serious pavement damage. Along with the increasing of pavement service life, driving speed, especially the road traffic volume and axle load, more and more CCP was destroyed in different degree in China (Li et al., 1998; Xie, 2000). The local damage is the main type of pavement failure results form nature disaster and the deficiencies involving pavement design, materials, construction technology, management and quality control. The further deterioration of local damage in pavement will affect the ride comfort and even destroy vehicles which may result in traffic accidents. It is very important to investigate feasible rapid repair materials and methods for the use and development of CCP. The rapid repair concrete for pavement must have many performances including very high-early strength for opening to traffic with 3.5 MPa flexural strength and 20 MPa compressive strength (Wang and Li, 2006), good anti-shrinkage and anti-cracking performance (Yang et al., 2000; Morgan, 1996), interfacial bond between old and new concrete surface for long term repair effect besides the basic properties (Morgan, 1996). High fluidity of concrete has greatly contributed to the repairing operation

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**Table 1.** Chemical compositions and mineral phases of cements (*w*/%).

| Cement | Chemical composition | | | | | | | | Mineral phase | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $R_2O$ | IL | $C_4A_3\bar{S}$ | $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ |
| PO | 21.06 | 6.96 | 2.41 | 60.89 | 1.79 | 2.12 | 0.89 | 3.43 | - | 38.28 | 30.27 | 13.7 | 7.17 |
| SA | 8.99 | 21.76 | 4.43 | 43.29 | 2.31 | 14.73 | 0.47 | 3.11 | 62.50 | - | 26.45 | - | 8.36 |

and for guaranteeing the repair quality (Palacios et al., 2009; Yang et al., 2000). Considering the stress characteristics of CCP and the actual specifications of cement concrete pavement design, flexural strength was used as control index and compressive strength as reference one in experiment test.

In a sense, high fluidity is conflict with super high-early strength (Chen et al., 2006). In this paper, focusing on the early flexural strength, interfacial bond, shrinkage and cracking performance, the preparing and testing of concrete with high-fluidity and super high-early strength for pavement repair was investigated. Based on the all kinds of experiments relevant with compatibility of cement and additives, strength, interfacial bond and freeze-thaw durability, HFESC was prepared and applied for pavement damage repair. Many kinds of materials, such as rapid hardening sulphoaluminate cement, magnesia-phosphate cement, early strength agent, fiber and polymers etc (Chung, 2004; Yang et al., 2000; Huang et al., 2004), can be used for concrete pavement repairing. In this paper, the concrete repairing material was prepared with rapid hardening sulphoaluminate cement, aminobenzene sulfonamide superplasticizer (ASS in short) and self-made RF admixture. The repair materials possessed of 3.5 Mpa 5 h-flexural strength, 20 MPa 5 h-compressive strength and 200 mm slump value and could meet the demand for traffic recovery. The laboratory test and field pavement repairing results revealed that the concrete has high fluidity and good mechanics performance and durability, which can be used in rapid repair of concrete pavement.

## METHODOLOGY

### Raw materials

#### *Cement*

Industrial blended Portland cement (PO in short, type PO42.5 according to GB175-2007) was used in this study, which produced in the Tianjin Cement Works by grinding Portland clinker and mixing with up to 3 mass (%) gypsum and about 6 - 15 mass% of the mixing materials including granulated blast furnace slag, fly ash and (or) volcanic ash etc. Rapid hardening rapid hardening sulphoaluminate cement (SA in short) was also used in experiment. The expected product of super high early strength concrete is ettringite in early hydration period and the hydration of SA can provide ettringite very early. The chemical compositions and mineral phases of cements used are shown in Table 1. The basic performance parameters of cements are listed in Table 2.

### Aggregates

Crushed limestone aggregate is used as coarse aggregate in concrete. Limestone is a natural stone material composed of more than 97 mass% calcium carbonate. The coarse aggregate is continuous grading with the size of 5 to 15 mm. The apparent density of the coarse aggregate is 2470 kg/$m^3$.

The river sand (quartz) with the fineness modulus of 2.5 and apparent density of 2610 kg/$m^3$ is used as fine aggregate in the study.

### Water

Tap water from municipal pipe network was used for production of concrete.

### Water reducing agent

After being selected through comparative experiment on the efficiency and compatibility of different water reducers, the commercial water reducer agent of ASS was used for the high fluidity of concrete.

### Early strength admixture

Early strength admixture is the key to preparing HFESC pavement repair material. Considering the requirement that HFESC must posses both high fluidity and super-high early strength, numerous kinds of early strength admixtures were investigated by comparative test on the early strength. The result showed that the super high-early strength of concrete was impossible to be prepared only relying on some one early strength agent without weakening the fluidity when using ASS as water reducer. Fortunately we have developed a ternarily compound early strength admixture (named RF admixture) composing of active powdered admixture and inorganic salts such as sulfate and nitrite (Chen et al., 2006), which obviously improved the early strength of concrete and also guaranteed the high fluidity of fresh concrete.

### Concrete mixtures

Experiment investigation on 28 groups of concrete specimen with basic different mix proportion was carried out for further research on the reasonable usage of RF admixture, fluidity of fresh concrete, compressive strength and flexural strength based on the optimizing experiments and analysis of the raw materials for concrete preparation. Based on the selected basic mix proportion form 28

**Table 2.** Basic performance parameters of cements.

| Performance | SA | PO |
|---|---|---|
| Fineness (80 μm sieve residue) (%) | 1.5 | 1 |
| Volume stability | Qualify | Qualify |
| Initial setting (min) | 40 | 220 |
| Final setting (min) | 100 | 380 |
| **Cement strength (MPa)** | | |
| 12 h Flexural strength | 6.4 | - |
| 12 h Compressive strength | 39.7 | - |
| 1 d Flexural strength | 7.2 | - |
| 1 d Compressive strength | 49.8 | - |
| 3 d Flexural strength | 8.6 | 5.1 |
| 3 d Compressive strength | 62.4 | 36.6 |
| 28 d Flexural strength | - | 9.4 |
| 28 d Compressive strength | - | 54.8 |

**Table 3.** Composition of concrete mixtures (kg/m$^3$).

| Mixture | PO | SA | RF | Water | Sand | Gravel | ASS |
|---|---|---|---|---|---|---|---|
| PO | 380 | - | - | 190 | 656 | 1090 | 42 |
| PO + RF | 335 | - | 45 | 190 | 656 | 1090 | 37 |
| SA | - | 380 | - | 190 | 656 | 1090 | 42 |
| SA + RF | - | 335 | 45 | 190 | 656 | 1090 | 37 |

groups, four kinds of concrete mixtures were further investigated. Table 3 shows the mix proportions of concrete.

#### Experimental methods

Early flexural and compressive strength of cement mortar were tested according to GB/T 17671-1999: Method of testing cements: Determination of strength.

The compatibility between binder (including cement and RF admixture) and ASS was analyzed through the time-dependent slump extension (Qin, 2000).

Fluidity of cement paste was measured according to GB 8077-2000: Methods for testing uniformity of concrete admixture. Early strengths of concrete were tested according to GB-T 50081-2002: Standard for test method of mechanical properties on ordinary concrete.

The fluidity of fresh concrete was measured according to GB-T 50080-2002: Test method for ordinary fresh concrete. Splitting strength of concrete was used for representing the interfacial bond strength based on the methodology proposed in Zhao et al. (1999). Half of the specimen after split test was placed in specimen mould and then cast HFESC in mould as the other half of specimen using for splitting test.

The specimen, with the size of 150×150×150 mm, was placed with the old-new concrete interface vertical after 28 days curing for testing.

The freeze-thaw durability was evaluated according to GB/T 50082: Standard for test method of long-term performance and durability of ordinary concrete (opinion soliciting draft).

## RESULTS AND DISCUSSION

### Early strength of cement mortar using RF

The effect of RF admixture on early flexural and compressive strength of cement mortar was investigated. The experimental results are shown in Figures 1 to 2. From the Figures 1 to 2, we can see that the early strength of cement mortar specimens using RF admixture is obviously increased, especially the specimen using SA and RF simultaneously. The flexural strength using RF is nearly 2 to 3 times of that without RF admixture, and the compressive strength is nearly 3 to 5 times. Obviously the strength of mortar increase when RF admixture used. The mechanism of RF admixture works to increase the mechanical strength can be explained as follows according to the components of RF admixture:

1. Nitrite increases the strength and accelerates the setting times of cement result from the accelerating hydration of cement as evident from the increased amounts of heat developed in its presence (Tritthart and Banfill, 2001; Montes et al., 2005).
2. Sulfate accelerates the hydration of cement clinker minerals such as $C_3A$, $C_3S$ etc. Almost immediately on

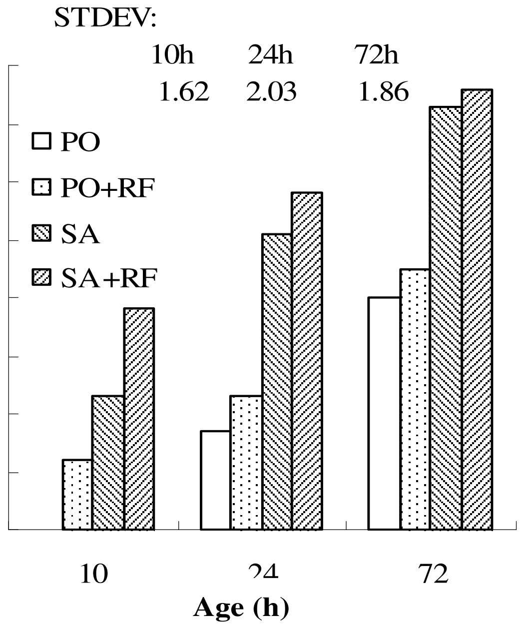


**Figure 1.** Early flexural strength of cement mortar using RF.

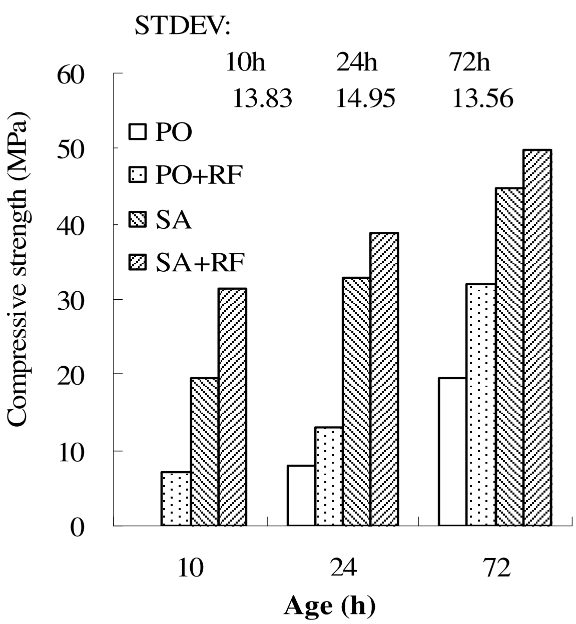


**Figure 2.** Early compressive strength of cement mortar using RF.

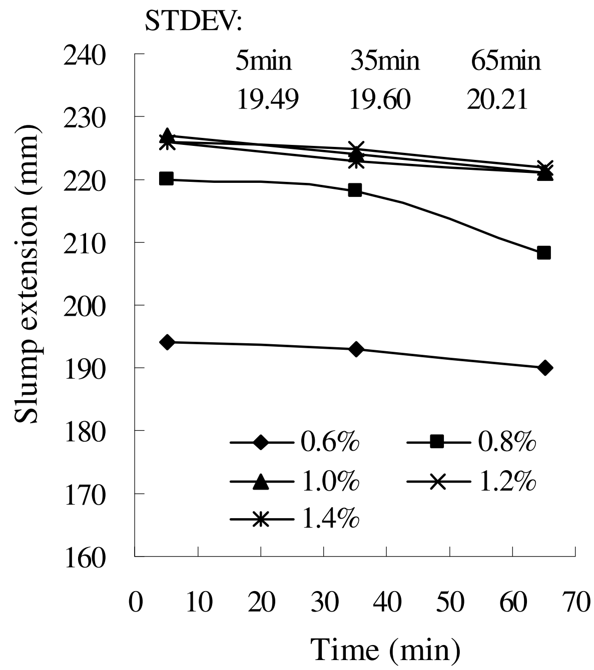


**Figure 3.** Slump extension of cement mortar using RF admixture.

adding water, some of the clinker sulphates and gypsum dissolve producing an alkaline, sulfate-rich, solution. Soon after mixing, the ($C_3A$) phase reacts with the water to form an aluminate-rich gel. The gel reacts with sulfate in solution to form small rod-like crystals of ettringite, and the strength of cement-based materials, especially the early strength, benefit from the generation of ettringite (Ramachandran, 1995).

3. The cementitious active powder in RF admixture mainly comprising of sulpho-aluminate and which accelerates the hydration of clinkers minerals in cement and thus the early strength and long-term strength of mortar(or concrete) increases (Gastaldi et al., 2007).

## Compatibility between admixture and cement

The results of time-dependent slump extension of cement paste without RF admixture were shown in Figure 3 and that of cement paste using RF admixture in Figure 4.

Figures 3 to 4 shows good compatibility between ASS, RF admixture and cement. The obvious increasing of fluidity by using ASS also occurs whether using RF admixture or not. It also can be seen from the figures that the optimum dosage of ASS is 1.0 mass% of cement.

According to Pei et al. (2008), the induction period of cement hydration with ASS has been delayed when compared to the plain cement; the exothermic rate is slow and the hydration peak lags behind. That is to say the ASS has the function of inhibiting the cement hydration. The inhibiting property of ASS in cement hydration results form its molecular structure with highly

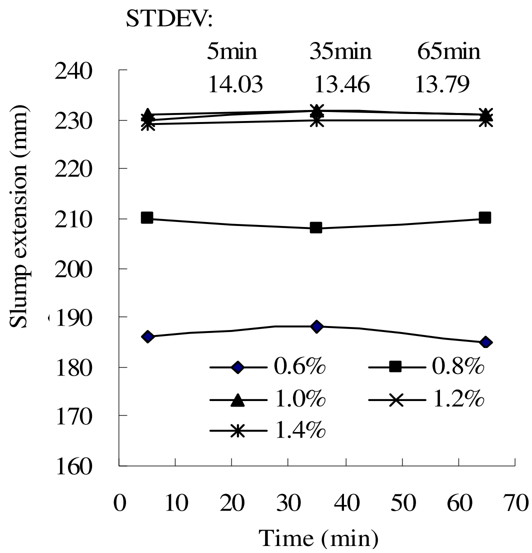


**Figure 4.** Slump extension of cement mortar without RF admixture.

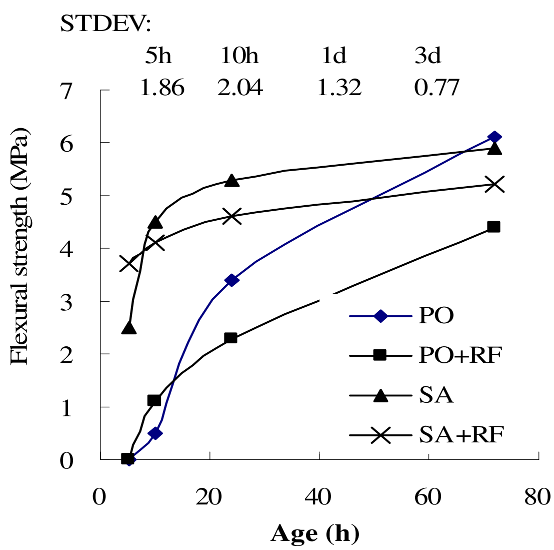


**Figure 5.** Early flexural strength of concrete.

branched chain, strong polarity and large space structures (Chen et al., 2004). Higher steric hindrance presences because of the rigid-vertica-chain absorption between cement and ASS results form the molecular structure. The coupling effect of steric hindrance and electrostatic repulsion gives AAS the excellent water-reducing and disperse properties. And the stable AAS-cement particles system and low time-dependent losing of ζ-potential makes cement paste with high fluidity and low slump loss.

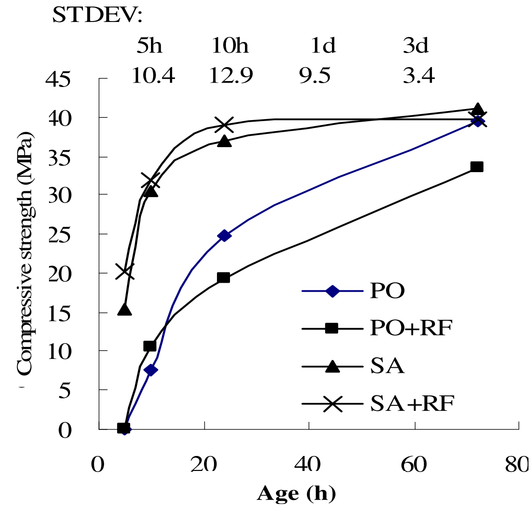


**Figure 6.** Early compressive strength of concrete.

## Early strength of concrete

The results of early strength of four kinds of concrete were shown in Figures 5 to 6. And the slumps of all the four concretes were over 200 mm.

According to Figures 5 to 6, it is difficult to get super-early high strength (with in 10 h) using Ordinary Portland Cement even the RF admixture is added in that the flexural strength is not enough to open traffic as early as 10 h. While using rapid hardened cement such as ASS, it is easy to open traffic in 10 h. As to HFESC prepared with ASS and RF admixture, its 5-h flexural strength is 3.7 MPa and enough to open traffic. The RF admixture, a ternarily compound composing of active powdered admixture and inorganic salts such as sulfate and nitrite, enhances the strength of ordinary cement hydration products.

## Interfacial bond strength

Figure 7 gives the experimental result of the splitting strength of concrete.

Figure 7 show that the using of RF admixture increases the interfacial bond strength between old concrete and new repair HFESC especially in early age. The enhancement of RF admixture on concrete early strength may result from the active effect of early strength compound in RF.

## Freeze-thaw durability

The frost resistance of concrete is essential for concrete

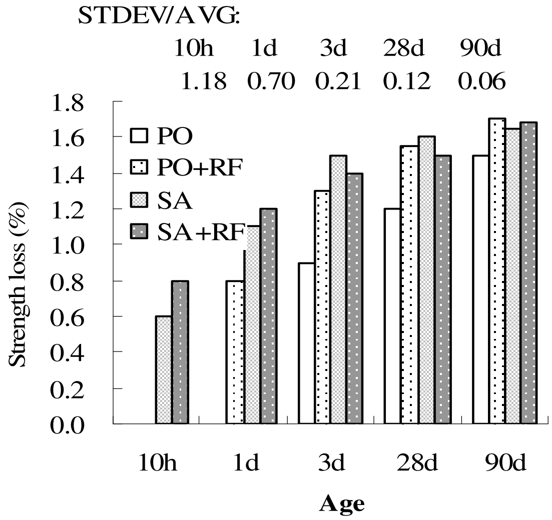


**Figure 7.** Interfacial bond strength of concrete.

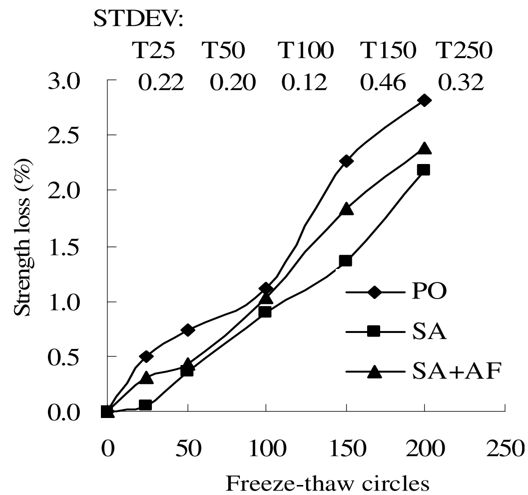


**Figure 8.** Freeze-thaw durability of concrete.

durability, especially in the area existing freeze-thaw circles. Figure 8 gives the freeze-thaw circle experiment results on the concretes prepared using cementitious materials of PO, SA and SA+AF respectively.

The experiment results reveal that group SA posses the best frost resistance performance and the strength loss of group PO is highest. All the strength loss of concrete after 200 times freeze-thaw circle is lower than 30%. The 12 mass% substitute of cement with RF admixture lower the freeze-thaw durability of concrete, which may result form the resoluble salt in RF admixture. The RF admixture mainly comprises of several kind of inorganic salts such as sulfate and nitrite salts which is resoluble in water. Comparing to the concrete without RF admixture using, the added salts will increase the saturation degree, expansion pressure and percolation pressure, thus aggravates the freeze-thaw damage on concrete (Neville, 1995; Cai et al., 1998).

## Conclusions

Based on the experimental research on RF admixture, water reducing agent, mechanical performance and freeze-thaw durability of HFESC, we can draw some conclusions as follows:

1. Good compatibility between rapid hardening sulphoaluminate cement, aminobenzene sulfonamide superplasticizer and RF admixture makes the preparing of HFESC possible.
2. The using of RF admixture and rapid hardening sulphoaluminate cement changes the hydration products of cement and increases the strength of concrete. The 5 h flexural strength of HFESC is over 3.5 MPa and 5 h compressive strength over 2 MPa.
3. The facts such as easy gain of materials for preparing HFESC, convenient construction and open to traffic as early as 5 h make HFESC a suitable pavement repair material. The application of HFESC in actual pavement repair also verifies the high performance of HFESC.

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