Research of a new liquid accelerator and its application

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Abstract

Shotcrete is an essential preliminary support means in New Austrian Tunneling Method (NATM) construction and plays a very important role in controlling the stability of surrounding rock. The accelerator is a necessary admixture in shotcrete and its quality can greatly affect shotcrete performance. There are existing powder accelerator which have problems of too large dosage, slow hydration reaction, uneven mixing, low coagulation promotion effect, while existing liquid accelerators have poor adaptability and concrete later stage strength attenuation. Therefor, this paper proposes a new liquid accelerator characterized by short initial and final setting time, small dosage, and good adaptability to cement. Laboratory tests and field tests are conducted to verify the influence of this liquid accelerator on shotcrete performance and compare it with the traditional accelerator. Adding this liquid accelerator can effectively improve the early strength and reduce the later strength loss of shotcrete, achieving better supporting effects for surrounding rock. During shotcreting in actual engineering, it is an ideal liquid accelerator for shotcrete, characterized by little rebound, no slurry shedding, and low dust.

Keywords

Liquid accelerator, shotcrete, preliminary support, tunnel engineering.

1. Introduction

In the construction of large-scale underground engineering, shotcrete as a necessary support means, is widely applied. Shotcrete is a kind of concrete set and hardened from a mix of cement, sand, stone, mineral materials, and admixtures in a proper proportion after being sprayed at high velocity onto a surface through the pipeline via compressed air or other force by using the shotcrete machine. Shotcrete can be quickly hardened to support surrounding rock without manual vibration.

The accelerator is a necessary admixture for shotcrete whose role is to quick setting and harden shotcrete, reduce rebound, prevent concrete from falling off due to the action of gravity[1,2]. The accelerator is classified into powdered and liquid accelerator. Its main types include alumina clinker-carbonate series, alumina clinker-alunite series, water glass series, low-alkali or alkali-free series[3,4]. Currently, shotcrete mainly adopts powdered accelerators in China, this kind of accelerator has a high level of alkaline, is highly corrosive to human body, and causes serious later strength reduction to shotcrete. The powdered accelerator, mainly applied to dry shotcrete, has a large amount of rebound and dust, cannot be uniformly mixed with aggregates. The liquid accelerator, mainly applied to wet-mix shotcrete, has instable quality, generally large dosage (6% to 10%), and immature supporting construction technology. Therefore, to resolve the preceding problems, a new liquid accelerator for shotcrete, with the dosage about 2%, has properties in all aspects superior to first-class goods stipulated in the *JC477-2005 Flash setting admixtures for shotcrete*, to better meet construction needs.

2. Development of Liquid Accelerator

2.1 Composition of Liquid Accelerator

This liquid accelerator is mainly prepared by KOH, NaOH, and $Al(OH)_3$ in a certain mole ratio, with the mole ratio of sodium to aluminum below 1.2. A certain amount of KOH, NaOH, and $Al(OH)_3$ solid powder is weighed, poured into a reaction vessel, and reacted with added quantitative water. The temperature is controlled above 120℃, the reaction time is 2 hours and then the mother liquor is available.

After the mother liquor is obtained, to improve its performance, other components are added to compound the mother liquor, including the polyacrylamide, triethanolamine, plasticizer, and stabilizer. The single solution cannot meet various requirements of shotcrete and therefore the mother liquor is compounded. Polyacrylamide is a kind of thickener used mainly to increase the cohesiveness of shotcrete and reduce rebound during construction; triethanolamine is a kind of early strength agent that can shorten the early setting time; the plasticizer is mainly to reduce water consumption and improve shotcrete strength; stabilizer can effectively improve the stability of the accelerator.

2.2 Functional Mechanism of Liquid Accelerator

As a kind of compound aluminate accelerator, this liquid accelerator has the mole ratio of sodium to aluminum below 1.2 and its active ingredient is mainly aluminate ion. Increasing the content of aluminate ion in the solution can give better play to accelerating effects. Meanwhile, reducing the mole ratio of sodium to aluminum can reduce the alkalinity of the accelerator.

The main component of this liquid accelerator is $KAl(OH)_4$. Given $Ca(OH)_2$, it reacts with gypsum in cement to produce calcium sulphoaluminate hydrate (ettringite) as well as potassium hydroxide and significantly reduces the concentration of soluble gypsum for delayed coagulation in cement mortar. Now, C_3A, a cement mineral component, is quickly dissolved into the solution and hydrated to hexagonal C_3AH_6 plates, thus accelerating the setting of cement mortar. A large amount of heat of hydration produced by the preceding reactions will also promote the reaction process and strength development. In addition, in the initial hydration stage, those ingredients produced in the solution such as $Ca(OH)_2$, SO_4^{2-}, and Al_2O_3 combine to produce high-sulfur calcium sulfoaluminate hydrate (ettringite) that is not only conducive to the development of early strength but also reduces the concentration of $Ca(OH)_2$, thus facilitating the hydration of C_3S. The produced calcium silicate hydrate gel interlaps to form crystals with the grid structure, thus boosting condensation[5-8].

The equations for the reaction between this liquid accelerator and cement-related ingredients are as follows:

$$2KAlO_2+3Ca(OH)_2+3CaSO_4+30H_20 \rightarrow 3CaO \cdot A1_2O_3 \cdot 3CaSO_4 \cdot 32H_20+2KOH$$

3. Experimental Studies on Material Properties

3.1 Experimental Material

The test cement adopts 425# ordinary Portland cement, with the main components of cement, see Table 1.

Table 1 Main components of cement

Components	Chemical formula	Shorthand notation	Mass fraction/%
Tricalcium silicate	3CaO·SiO2	C3S	17.83
Dicalcium silicate	2CaO·SiO2	C2S	55.24
Tricalcium aluminate	3CaO·Al2O3	C3A	10.12
Tetra-calcium aluminoferrite	4CaO·Al2O3·Fe2O3	C4AF	7.81
Calcium sulphate dihydrate	CaSO4·2H2O	CSH2	8.0

3.2 Test Method

(1) Refer to the *JC477-2005 Flash setting admixtures for shotcrete* standard (hereinafter referred to as the Standard) in the building material industry.

(2) Get 400g cement with the water-cement ratio of 0.4. The additive amount of water needs to deduct the water content in the liquid accelerator. The normal consistency and setting time tester of cement paste is adopted to measure the initial and final setting time of cement paste with different dosages.

(3) Get 900g cement and 1350g standard sand, with the water-cement ratio of 0.5, mix the mortar uniformly, add the liquid accelerator, and quickly stir the cement mortar for 40 to 50 seconds. Make a 40 mm×40 mm×160 mm trial model with cement mortar, maintain it in the standard curing room at the temperature of 20℃±2℃ and with humidity above 95%, measure its strength after one day or 28 days, and calculate the strength ratio.

3.3 Test Results and Analysis

Setting time of cement with different dosages

The liquid accelerator has different setting time with different dosages. The initial and final setting time of cement paste with the dosages of 1.5%~4% of this liquid accelerator are to be listed, see Table 2.

Table 2 Initial and final setting time of cement paste

Accelerator Dosage/%	Water-cement ratio	Setting time/s	
		Initial setting	Final setting
1.5	0.4	145	270
2.0	0.4	90	200
2.5	0.4	110	210
3.0	0.4	135	230
3.5	0.4	150	265
4.0	0.4	162	280

According to Table 2, the dosage of 1.5%~4% of the liquid accelerator, all meet the requirements of first-class goods stipulated in the Standard. Table 2 also shows that this liquid accelerator has the best accelerating effects when the dosage is 2%. The initial and final setting time is 1min30s and 3min20s respectively.

Setting time of cement with different water-cement ratios

The water-cement ratio greatly affects the cement setting time. The greater the water-cement ratio, the worse the accelerating effects.The initial and final setting time of cement with different water-cement ratios and the same accelerator dosage 2%, see Fig. 1.

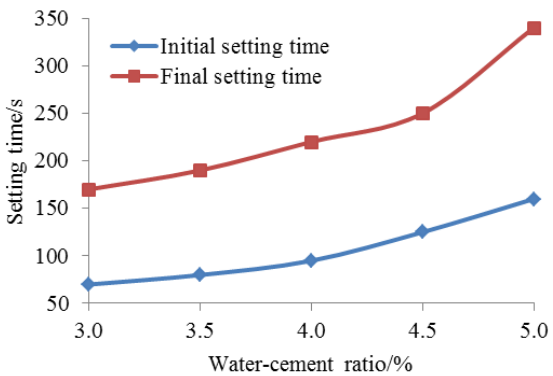

Fig. 1 Water-cement ratio change curves of setting time

According to Figure 1, as the water-cement ratio increases, the initial and final setting time is prolonged. In dry-mix shotcrete, the water-cement ratio is controlled by adjusting the water volume by the shotcrete manipulator based on his observation. The mixture water consumption in dry-mix shotcrete should not

only make the shotcrete have better compaction and adhesiveness but also reduce rebound materials. A too large water-cement ratio usually causes shotcrete to fall off while a too small water-cement ratio causes stratification to mixtures. In wet-mix shotcrete, the water-cement ratio is specific and needs to meet properties such as the slump and pumpability.

Strength of cement mortar with different dosages

The compressive strength of cement mortar with different dosages is obtained. As the accelerator dosage increases, the later strength loss tends to increase. However, with the dosage ranges from 1.5% to 4%, the later strength loss will not exceed 10%. The compressive strength of cement mortar,see Table 3.

Table 3 Compressive strength of cement mortar

Accelerator dosage/%	Compressive strength/MPa		28d compressive strength ratio/%
	1d	28d	
0	7.8	47.8	100
1.5	13.6	46.9	98.1
2.0	13.9	46.1	96.4
2.5	14.5	45	94.1
3.0	15.1	44.6	93.3
3.5	15.8	43.7	91.4
4.0	14.2	43.1	90.2

4. Engineering Application

The field test is conducted on the developed new liquid accelerator in Changgang tunnel of Fushou Highway. This tunnel is class IV surrounding rock, the strength grade of shotcrete is designed to C25 and the shotcrete layer depth to 25 cm. Fine aggregate uses hard medium-coarse sand with the fineness modulus greater than 2.5. Coarse aggregate uses crushed stone with the particle diameter ranging from 5 to 10 mm. The dry concrete mix proportion of cement, sand, stone is 469:912:912, the water-cement ratio is designed to 0.45, adopts Huangteng powdered accelerator, the dry shotcreting machine adopts 7 m^3. The dry powdered accelerator has the actual dosage reaching 15%, about 40% rebound, and large amount of dust during spraying. The field dry-mix shotcrete, see Fig. 2.

Fig. 2 Field dry-mix shotcrete

This liquid accelerator is used together with a new shotcreting method. Based on the original dry-mix shotcrete technology, a high-pressure accelerator dosing device is added, which can provide 1.2 MPa pressure to pump the liquid accelerator to the high-pressure water pipe and accurately control the dosage of the liquid accelerator. The mixture of the liquid accelerator and water contacts with the concrete mix at the nozzle and are sprayed onto the surface together. By using canvas trial to measure rebound of new shotcrete technology, the rebound rate is 8%. The sprayed surface has bright luster, without slurry shedding. The new field shotcrete technology, see Fig. 3.

Fig. 3 New field shotcrete technology

During field shotcrete, the jet molding test is conducted to measure the strength of shotcrete. The specimen is a 150 mm^3 cube template that is grounded flush after tunnel shotcreting. Then, it is maintained in the lab incubator and the 1d and 28d uniaxial compressive strength are measured, see Table 4. The test results show that shotcrete using this liquid accelerator has a higher compressive strength.

Table 4 Compressive strength of shotcrete

Number	Age/d	Compressive strength/MPa	
		Single block value	Group value
1		13.4	
2	1	12.5	12.6
3		11.9	
1		33.5	
2	28	31.6	32.4
3		32.2	

5. Conclusion

(1) The dosage of this liquid accelerator is small, and it is an efficient compound liquid accelerator. When the dosage is 2%, the quick setting effects are optimal. The initial and final setting time of neat cement paste is within 2 minutes and 4 minutes respectively.

(2) This liquid accelerator can increase the cohesiveness of shotcrete and can effectively reduce resilience and dust during shotcreting. Meanwhile, it can increase the strength of adhesion with surrounding rock, and achieve better supporting effects.

(3) This liquid accelerator can effectively reduce the later strength loss of shotcrete and ensure that the strength loss is controlled within 10%.

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