

Support technology of high pressure hydraulic shotcrete and its application in tunnel engineering

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Abstract. Shotcrete technology is one of the necessary part of support system in tunnel engineering, and the support effect of shotcrete is getting more and more attention. We improve the materials and technologies and propose a new shotcrete supporting method, high pressure hydraulic shotcrete. The high pressure hydraulic parameters of C20, C25 and C30 concrete is studied. Several key factors and problems of the parameters are expounded. The engineering application shows that, compared with ordinary shotcrete technology, high pressure hydraulic shotcrete can effectively reduce the shotcrete resilience and the content of dust, and the later strength loss of shotcrete is less than 10%, which has a good popularization and application value.

1. Introduction

Shotcrete, as a part of primary support in tunnel engineering, plays an important role in controlling deformation of surrounding rock. Shotcrete is that using a concrete spraying machine with compressed air or other power, sprays a certain proportion of sand, stone, cement and accelerator to the sprayed surface, and forms a dense layer of concrete structure. Shotcrete can setting in a short period of 10 minutes and has strength, so it can effectively control the deformation of surrounding rock during tunnel excavation. Shotcrete technology is mainly used in support system of underground engineering, water conservancy engineering, geotechnical engineering, slope engineering, and usually it is used together with anchor, which is identified as spray anchor [1-2].

In 1914, the United States took the lead in the construction of jet cement mortar. In the 1930s, due to the improvement of concreting equipment, people began to try to use shotcrete to support the tunnel, because there was no accelerator at that time, the setting time of shotcrete was too slow to bond with surrounding rock, resulting in the collapse of concrete. In the 1940s, Switzerland, Germany and Japan produced concrete spraying machine that can spray coarse aggregates and they developed accelerators at the same time, which enabled shotcrete technology to be truly applied to engineering construction. Since then, many countries have begun to use this technology in civil engineering. Since the 1960s, shotcrete technology has been used in mine and tunnel engineering in China.

2. high pressure hydraulic shotcrete technology

At present, shotcrete mainly consists of two types of spray, namely dry shotcrete and wet shotcrete. Dry shotcrete is that using a concrete spraying machine with compressed air or other power, transfers a



certain proportion of sand, stone, cement and powder accelerator to the spray nozzle, where to add the water, then sprays the mixture to sprayed surface. Wet shotcrete is that using a concrete spraying machine with compressed air or other power, transfers a certain proportion of sand, stone, cement and water to the spray nozzle, where to add the liquid accelerator, then sprays the mixture to sprayed surface [3].

Because dry shotcrete has the advantages of simple operation, long conveying distance, convenient cleaning and easy construction, the dry shotcrete is still used in most of the engineering project in China. However, the shotcrete resilience and the dust content of the dry shotcrete are relative large, the shotcrete resilience is about 30%~50%, and the dust content is too large to see people after 30 mins of spraying. At the same time, in the field construction of dry shotcrete, the powder accelerator cannot fully react and the dosage is not uniform, resulting in a large dosage, sometimes the dosage can reach 15% of the cement, which greatly affects the later strength of shotcrete. Too many dosage makes crack generate easily in the concrete, which has great influence on the stability of surrounding rock. The advantages of wet shotcrete are that the shotcrete resilience and the dust content are low, and the concrete dispersion is small. But the wet spraying equipment is expensive, the cleaning is troublesome, and the operation is very inconvenient. In addition, for the mixed concrete, if it is not used for a long time, it is easy to coagulate and harden. What's more, the mix proportion of concrete is not easy to control. In actual shotcreting, concrete trucks are required to work all the time. In short, wet shotcrete has the characteristics of difficult construction, difficult control and high cost. Therefore, dry shotcrete technology [4-8] is still used in most engineering projects.

In view of the above situation, a new type of shotcrete technology, high pressure hydraulic shotcrete, is proposed. On the basis of the technology of dry shotcrete, liquid accelerator is added instead of the powder accelerator, and a mixing device is designed to make concrete and liquid accelerator fully mixed. The work process of the proposed technology is shown in Figure 1. The liquid accelerator enters the water pipe through a high-pressure device. The water and the liquid accelerator are mixed with the concrete aggregate at the spray nozzle and then sprayed to the sprayed surface.

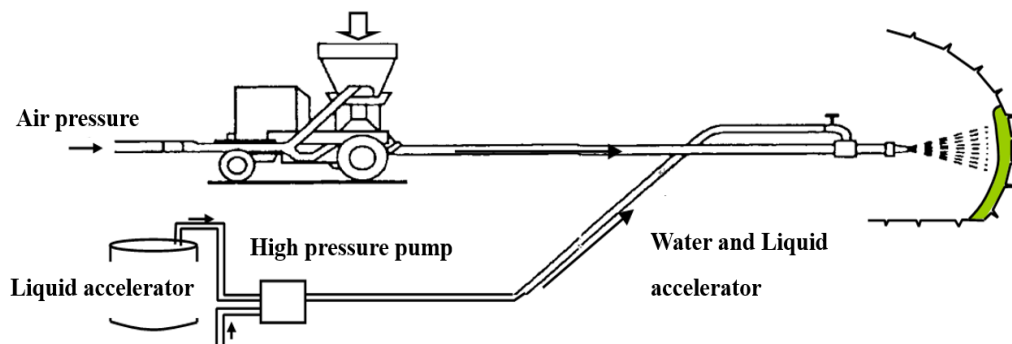


Figure 1. Work process of the high pressure hydraulic shotcrete technology

The high pressure hydraulic shotcrete technology can effectively reduce the shotcrete resilience and the dust content during construction. The dosage of liquid accelerator can be precisely controlled to ensure the quality of shotcrete. The adding content of the liquid accelerator is about 2%, and the strength loss of concrete is less than 10%. Engineering test shows that the shotcrete resilience is about 10% using this new shotcrete technology.

3. laboratory test

Laboratory tests are carried out to study the new shotcrete method. Firstly, a new liquid accelerator is developed. Secondly, the construction technology is improved. Thirdly, the equipment is developed. Finally, the laboratory test is carried out.

3.1. Development of liquid accelerator

Accelerators are mainly divided into two kinds: powder and liquid, and the powder accelerator is mainly used in dry shotcrete technology. The earliest kinds of accelerators in China are also powdery. Red Star Type I, 711 and 782 are the earliest accelerators developed in China. They are still used in engineering. The liquid accelerator is mainly composed of aluminate, sodium silicate, alkali free and low alkali [9-14]. Because the quality of liquid accelerator cannot be guaranteed, it is easy to produce precipitation and crystallization, and there are few ideal liquid accelerator on the market. Therefore, we have independently developed liquid accelerators and produced a high speed accelerator.

The liquid accelerator is mainly composed of potassium aluminate and several effective components. The adding content of the accelerator is 2% of cement quality, the initial setting time is about 2 minutes, and the final setting time is about 4 minutes, which are better than the requirements of national first-class products of China [15]. The new liquid accelerator is tested with the cement of Shanshui Company and the setting time of cement is shown in Table 1.

Table 1. Setting time of cement with different content of liquid accelerator

| Content/% | Water cement ratio | Initial setting time | Final setting time |
|-----------|--------------------|----------------------|--------------------|
| 1.5 | 0.4 | 2min40s | 5min40s |
| 2.0 | 0.4 | 2min20s | 4min20s |
| 2.5 | 0.4 | 1min40s | 3min50s |
| 3.0 | 0.4 | 1min30s | 3min20s |
| 3.5 | 0.4 | 2min10s | 4min15s |
| 4.0 | 0.4 | 2min30s | 4min30s |

According to table 1, under the condition of low dosage, the proposed liquid accelerator can make cement condense quickly. At the same time, the new liquid accelerated is tested with the mortar strength test to study the loss rate of later strength. The result is shown in Table 2. As shown in Table 2, when the adding content of proposed liquid accelerator is within the range of 1.5%~3%, the strength loss is less than 10%. In the actual engineering construction, the content of the liquid accelerator is generally 2%. Low dosage can effectively reduce the late strength loss and reduce produce of cracks.

Table 2. Compressive strength of cement mortar with different contents

| Content/% | Compressive strength /MPa | | 28d compressive strength ratio /% |
|-----------|---------------------------|------|-----------------------------------|
| | 1d | 28d | |
| 0 | 7.8 | 47.8 | 100 |
| 1.5 | 13.6 | 46.9 | 97.2 |
| 2.0 | 13.9 | 46.1 | 94.5 |
| 2.5 | 14.5 | 45 | 92.3 |
| 3.0 | 15.1 | 44.6 | 90.4 |
| 3.5 | 15.8 | 43.7 | 87.6 |
| 4.0 | 14.2 | 43.2 | 84.5 |

3.2. Development of equipment

In order to add liquid accelerator into high-pressure water pipe and control its dosage accurately, a quantitative device is needed. The device have high pressure with 1.2 MPa, and water pressure in construction is generally 0.4 MPa, high pressure can make liquid accelerator atomization, so that it can mix with water well. The device has several openings to control the addition of liquid accelerator by adjusting the opening. Figure 2 is the prototype of the device.



Figure 2. Prototype of the equipment

The Mix proportion of C20~C30 is obtained through calculation, and it shows in Table 3.

Table 3. Mix proportion of shotcrete

| Strength grade | Cement | River sand | Ravel pebble | Water | Liquid accelerator |
|----------------|--------|------------|--------------|-------|--------------------|
| C20 | 400 | 802 | 802 | 165 | 8.0 |
| C25 | 435 | 882 | 883 | 187 | 9.6 |
| C30 | 486 | 915 | 875 | 209 | 12.2 |

4. Engineering application

Connecting the equipment, field spray test is carried out in the tunnel section. The total length of the tunnel is 3 m, the height of the tunnel is 9 m and the width is 11 m. The wind pressure is 0.2MPa and the water pressure is 0.15 MPa. When spraying side wall, the content of liquid accelerator is controlled at 1.5%, when spraying arch waist and vault position, the content of liquid accelerator is 2.5%.

The spraying time is 4 hours and the total volume of concrete is 20 m³. The spraying efficiency is 30% higher than that of ordinary dry shotcrete and the measurement of shotcrete resilience is 9.5%. Figures 3 and 4 are field dry spray and new process spray photographs. Figures 3 and 4 are photographs of on-site dry shotcrete and new high pressure hydraulic shotcrete, respectively. As can be seen from Fig. 3 and Fig. 4, the amount of dust produced by the high pressure hydraulic shotcrete is much lower than that by the traditional dry shotcrete.



Figure 3. Field application of dry shotcrete technology



Figure 4. Field application of high pressure hydraulic shotcrete

After the injection, the amount of resilience is measured. Shotcrete resilience refers to the ratio of the concrete loss to the total amount of spraying concrete in the construction process. Shotcrete resilience is equal to that V_1 divides V . Where, V is the total volume of spraying concrete and V_1 is the loss volume of spraying concrete. The shotcrete resilience of the new technology is 9.6% and that of the traditional technology is 36%.

5. Conclusion

(1) The new technology of high pressure hydraulic shotcrete can effectively reduce the shotcrete resilience and the content of dust, which can improve the working environment and improve the labor efficiency. The new technology is simple so that it is suitable for field environment and save the construction cost.

(2) The use of liquid accelerator can effectively reduce the dust when spraying, and can mix with concrete evenly. In the case of very small mixing content, it can effectively reduce the late strength loss of shotcrete. The new type of liquid accelerator is developed independently. The dosage is about 2%, the initial setting time is about 2 minutes, and the final setting time is about 4 minutes. The quality is obviously better than that of the existing liquid accelerator in the market.

(3) The device of adding liquid accelerator is compact, light and easy to operate. It can accurately control the amount of liquid accelerator, ensure the mechanical indexes of shotcrete, improve the quality of shotcrete and enhance the supporting effect.

(4) The application of shotcrete technology is more and more extensive, and its performance requirements are more and more high. Mix ratio design is the most critical step of shotcrete. The influence of water cement ratio, sand ratio and cement dosage must be considered comprehensively.

(5) The use of high pressure hydraulic shotcrete technology can greatly reduce the construction cost and has a good promotion and application value.

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