

# Research and Development of Shotcrete

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## ABSTRACT

In recent decades, shotcrete technology has developed rapidly in civil engineering. A lot of practice at home and abroad has proved that shotcrete has shown its unique functions and obvious benefits in the engineering fields such as supporting lining of mine roadway and underground engineering, reinforcing and reinforcing of building structure, stabilizing of rock and soil slope, building of thin wall structure with complex shape and water transmission and filling structure. It can be expected that with the continuous development of transportation, energy and material industry, a large number of urban underground engineering and complex public buildings are constructed, and the increasing number of building structure reinforcement projects, the application field of shotcrete will be increasingly broad. This paper mainly introduces the research progress, construction technology and future development direction of shotcrete in recent decades.

## KEYWORDS

Shotcrete; Construction technology; Direction of development

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## 1. INTRODUCTION

Shotcrete is a kind of quick-setting concrete used to reinforce and protect structures or rock surfaces. The technology is with the help of spraying machinery, the use of compressed air or other power, will be in accordance with a certain ratio of cement, sand, gravel and admixtures and other mixes, sprayed through the nozzle to the sprayed surface, within a few minutes of hardening and shaping of the concrete reinforcement reinforcement materials.

The application of shotcrete technology has a history of 100 years, with the earliest shotcrete mortar construction in the United States in 1914. Early application of spraying was very immature, in the 1940s, the spraying equipment can only spray coarse aggregate, but due to the slow setting and hardening of the concrete, the spraying thickness is very thin, and for the top wall of the concrete can not be bonded. the late 1940s have developed the quick-setting agent this kind of admixture, which can make the cement fast setting and hardening, which greatly improves the thickness of the spraying, reduces the rebound of the spraying and the early strength of the concrete. This greatly increased the thickness of the shotcrete, reduced the rebound and the early strength of the concrete.

In the late 1960s, with the introduction of the new Austrian construction technology, China began to use shotcrete technology, and in the process of using it, a series of relevant specifications and operational construction guidelines were formulated. Admixtures for shotcrete were also successfully developed in the same period, such as the earliest red star I type, 711 type and 782 type quick-setting agent, these are powdered quick-setting agent, the mixing amount is generally 4% to 6% of the mass of cement, the initial setting time of the cement slurry is generally 4 min, and the final setting time is about 7 min. At present, China mandatory implementation of wet spraying technology. Dry spraying

of concrete causes serious pollution to the environment, damages the body of construction workers, and causes a lot of waste due to the large amount of rebound and dust.

At present, the application range of shotcrete is more and more extensive, such as perimeter rock support, slope support, thin-shell construction of large buildings, building repair, deep foundation pit support and structural reinforcement, emergency repair and other projects. With the improvement of spraying machinery, the application of new materials and new technology, shotcrete is developing towards high efficiency, no pollution, high support strength, and better applied to the construction site [1-4].

## **2. MATERIALS AND PROPERTIES FOR SHOTCRETE**

The materials used for shotcrete mainly include cement, aggregate and quicklime, and the properties of concrete are strength, deformation, durability, etc.

### **2.1. Cement**

Cement is generally P.O42.5 ordinary silicate cement, do not mix fly ash or slag in cement, otherwise it will affect the performance of quick-setting agent. For the construction site under special environment, choose cement according to demand, such as the site temperature is high, use high aluminum cement. When there is groundwater at the site and the groundwater contains sulfate, use sulfate-resistant cement. Choose the right cement according to the requirements of the site to ensure the smooth progress of the construction. The cement should be sealed and stored to avoid its weathering and deterioration. If weathered cement is used, even if quick-setting agent is added, it will be ineffective, and its setting time and strength of sprayed concrete will be significantly affected, so that the quality will be reduced.

### **2.2. Aggregate**

Aggregate used for sprayed concrete should be the same as ordinary concrete, which must be clean, hard, well-graded, and free of long and thin stone flakes, dust, mud powder and organic matter. Sand: medium-coarse sand, well-graded particles, fineness modulus of 2.5 or more, less mud, less water. Stone: generally use pebbles or gravel, particle size of 5mm ~ 10mm, particle size is too large, easy to block the jet pipe, and easy to cause rebound. Usually the best pebbles to reduce the wear and tear on the jetting machine and material pipe. Try to avoid the use of stones containing reactive silica, so as to avoid alkali aggregate reaction with quicklime.

### **2.3. Quicklime**

The role of quick-setting agent is mainly to make the concrete set quickly, so that in the process of spraying, it can make the concrete reach a certain thickness, especially in the spraying of the perimeter arch, if the concrete setting time is too long, it will slump, or can't be constructed at all. After adding quick-setting agent, the concrete is set within 10min, which increases the bonding force with the surrounding rock. Quick-setting agent can also improve the early strength, the strength of one day can reach more than 10 MPa, and play a certain role in supporting the surrounding rock.

The reaction mechanism of quick-setting agent is usually considered that the gypsum in the cement is consumed after mixing with quick-setting agent to produce a kind of gel material, or form calcium alumina. Gypsum in cement plays a retardation role in cement hydration, and when consumed, it can promote the rapid hydration of the four components in cement. Therefore, it can make the cement harden quickly. It takes 6 h for ordinary cement to reach final setting, and after adding quick-setting agent, the final setting time is shortened to 10min~10min, which can be seen that quick-setting agent plays a big role.

Quick-setting agent according to the form can be divided into liquid quick-setting agent and powder quick-setting agent, liquid quick-setting agent is divided into two categories of organic and inorganic. Common liquid inorganic quick-setting agent is water glass quick-setting agent, such as sodium silicate, aluminate system (such as, sodium aluminate, potassium aluminate); powder quick-setting agent, including traditional quick-setting agent, such as powdered sodium aluminate, sodium carbonate, etc., cement quick-setting agent, instantaneous coagulation cement, acidic quick-setting agent. China's national specifications provide quick-setting agent to meet the design requirements, before use should be done with the adaptability of the cement test, qualified products within 5min of the initial setting time, the final setting time of 10min, the late strength retention rate of more than 70%, the amount of mixing is generally in the range of 4% to 8%, the mixing of powdered quick-setting agent requirements in the range of 4% to 6%, the mixing of non-alkali liquid quick-setting agent is relatively high, generally 6% to 8%. Quick-setting agent can't make the cement appear quick-setting, and the dosage is too large for the late strength loss is more serious.

## 2.4. Properties of sprayed concrete

The properties of concrete mainly include strength, deformation, and durability [5].

### 2.4.1. Design basis strength

Sprayed concrete strength grade or design base strength varies according to function, section shape and other structural conditions, loading conditions, etc., generally more compressive strength is used to classify its grade and give the design base strength at the same time. Since nowadays sprayed concrete is not only an important component of initial support, but also an important part of permanent support. Therefore, in many countries have stipulated the design strength of sprayed concrete, using the same strength as the lining concrete. Sprayed concrete design benchmark strength to meet the following formula.

$$\gamma_p f_{ck} / f_{cp} \leq 1.0.$$

Among them,  $f_{ck}$  is the design strength of sprayed concrete;  $f_{cp}$  is the compressive strength of sprayed concrete, generally found through experiments;  $\gamma_p$  is the safety coefficient of  $f_{cp}$  accuracy, generally 1.0 ~ 1.3.

### 2.4.2. Deformation of sprayed concrete

Deformation of shotcrete mainly creep deformation and shrinkage deformation, shotcrete in the hardening process is often accompanied by volume changes, in the humidity of the medium of the hardening of the volume produced by the shrinkage, known as shrinkage deformation. Creep and shrinkage change with age, temperature, and time. This condition is reduced or even an increase in volume may occur if the cement is under water or in a humid environment. Due to the addition of quicklime, the hydration of cement is accelerated and at a later stage the concrete undergoes drying and shrinkage. The main factors affecting the shrinkage of shotcrete are quicklime and curing conditions.

### 2.4.3. Durability

At present, the requirements for concrete no longer emphasize high strength, but high durability of concrete, that is, the service life should be long, can resist a variety of erosion, alternating hot and cold damage, high impermeability and so on. High permeability mainly depends on the low porosity and dense pore structure, the amount of cement in the shotcrete should be relatively high, high sand rate, water-cement ratio is small, or mixed with some mineral materials to increase the degree of compactness. Shotcrete in the construction process, will be with a certain amount of air, air content is generally 2.5% ~ 3.5%, so the formation of air bubbles in the shotcrete, the presence of air bubbles can enhance the frost resistance of concrete. On the contrary, the frost resistance of shotcrete can be

reduced if weak and easily absorbed aggregates are used, or rebound materials are mixed in the spraying process, and improper maintenance [6].

### **3. CONSTRUCTION PROCESS OF SPRAYED CONCRETE LITERATURE REFERENCES**

#### **3.1. Dry Mixing Construction Process**

Dry materials are mixed in the mixing station and then transported to the nozzle with compressed air. At the nozzle, water, liquid admixture and quick-setting agent are introduced and then sprayed out immediately under the air pressure of 0.6~0.7MPa.

Dry spraying construction process is simple and convenient, and requires less construction equipment, as long as there are forced mixing machine and dry spraying machine. Dry spraying construction conveying distance is long, the construction arrangement is convenient and flexible, the conveying distance can be up to 300m, the vertical distance can be up to 180 m. The quick-setting agent can be added in advance before the jetting machine, and the mixing is more uniform. The amount of dust and rebound on the working surface is large, the working environment is poor, and there is a pulse phenomenon when spraying, and the uniformity of the sprayed material is poor. The mixing water can only be applied at the nozzle, the actual water-cement ratio is not easy to control accurately, the construction experience of the sprayer and the coordination ability of the field strain have a great impact on the quality of spraying, the quality of sprayed concrete is sometimes not stable enough, the design ratio is affected by the impact of rebound and the actual concrete attached to the ratio of the larger difference.

#### **3.2. Wet Mix Construction Process**

In addition to quick-setting agent, all the materials in the mixing station mixing, and then transported to the nozzle with a concrete pump, in the nozzle at the with quick-setting agent, in 0.6 ~ 0.7MPa compressed air, immediately sprayed.

Wet spraying method of spraying concrete mix can be mixed with enough design water, fully mixed, is conducive to the full hydration of cement, and thus the concrete strength is higher, and its water-cement ratio can be more accurately controlled but more water than the dry spraying method. The quick-setting agent can not be added in advance. Coagulant generally can not be added in advance, should be added only after the spraying machine, and dust, rebound are less, the production environment is good. Wet spraying equipment is more complicated, and it is more difficult to add quick-setting agent. Its conveying distance and height is much smaller than the dry spraying method, and the arrangement of the spraying system needs to be closer to the working surface. Because of the mixture of water beforehand, so the construction of the middle of the machine shall not be stopped. After stopping spraying, the equipment should be flushed clean as soon as possible.

#### **3.3. Cement-Coated Sand Method (SEC)**

Dry spraying and wet spraying have their own advantages and disadvantages. Over the past decade, the sand cement method developed in Japan has absorbed the advantages of both methods with large output, high efficiency, long pressure delivery distance, uniform spraying quality, high strength, low rebound rate, low dust, etc. It is favorable to work under the condition of gushing water, and it has been widely used both at home and abroad. SEC sprayed concrete is a new construction method in which the sprayed aggregate is divided into two lines for different treatments and then pressed into the mixing pipe for mixing, and then sprayed onto the working surface by linking the mixing pipe and nozzle [7]. The key aspect of the SEC method is the preparation of shelling cement mortar.

It is the shelling cement with low water-cement ratio, high strength state wrapped around the surface of the sand particles to strengthen the adhesion of the interface, to make up for the defects of the traditional cement mortar in the cement paste and sand surface adhesion is not high. The key link in the preparation of shell-making cement mortar is to keep the water content of sand surface at 4%~6% and control the amount of water added twice. SEC sprayed concrete has a great improvement in performance over ordinary sprayed concrete. However, the current method is worth noting the following issues: 1) the wet road in the sand water content to maintain 4% ~ 6% is necessary; 2) two supply lines to match the flow; 3) dry road in the mechanical wear; 4) the use of robotic nozzle.

### **3.4. Double Parallel Method**

Double wrapping and juxtaposition method of shotcrete in the operation mode is also the use of two lines to convey sprayed materials, but it is with the SEC sprayed concrete the essential difference is that it will be SEC method of pure dry road into a slightly wet road, but also the formation of a kind of wrapped ash material line. So that the two transmission lines have the role of cement wrapping, so called "double wrapping parallel method". Its advantages can be reflected in the strength improvement, cement dosage reduction, dust control, rebound rate is further reduced in several aspects, but at the same time it is the material requirements significantly improve the construction organization, personnel management more scientific requirements.

### **3.5. Tide Material Mixed With Slurry Method**

Tide mixing slurry shotcrete process is summarized in the tide spraying method and SEC method developed on the basis of practical experience, the purpose is to use the traditional dry spraying method of equipment and operation but can achieve the effect of the SEC method of a method. It also has two pipelines for operation, one is for the shell-making tide mixture (similar to the slightly wet line in the double wrapping parallel method), and the other is for the cement slurry. Due to the good viscosity of the cement slurry, it can be better pasted and fused with the shell-making tide mixture at the nozzle to improve the strength; another advantage is that its equipment and operation can reach the simplicity of the dry-spraying method. The problems it has are also focused on the optimal design of the ingredients.

### **3.6. Existing Problems**

At present, some domestic projects still use dry spraying process in large quantities, because of its low cost and simple operation. However, in the spraying construction, dry spraying concrete rebound and dust amount is very large, the construction environment is poor, and at the same time cause a lot of loss of concrete. Powdery quick-setting agent in use, add uneven, and the mixing amount is large, the late loss of strength of the concrete has a greater impact on the concrete, it is easy to cause cracking of sprayed concrete, bringing safety hazards to the project.

Wet spraying of concrete operation process is complex, requiring precise concrete ratio, cleaning is not convenient, high cost, and equipment is large, in the field is not good operation. For various reasons, it can not be widely promoted. On this basis, a new process is proposed, which can effectively improve the above defects, adding liquid quick-setting agent on the basis of dry spraying, so as to achieve the effect of wet spraying [8].

## **4. DEVELOPMENT DIRECTION OF SHOTCRETE**

As the shotcrete technology has the characteristics of material saving, labor saving, high efficiency, low cost, good effect, etc., it has been widely used in underground engineering, geotechnical engineering, municipal engineering, especially water conservancy engineering, tunnel engineering

construction, often using anchor shotcrete for early support, rapid stabilization of the cave wall, you can continue to carry out the blasting excavation, greatly reducing the possibility of landslides. With the improvement of the construction process, the development and use of new and more perfect function of the spraying machine, shotcrete as a new type of material, a new type of support structure and a new construction technology will have a more extensive development prospects.

3D printing technology is one of the most important and dynamic leading edge technologies today. 3D printing technology in the field of metal materials has been commercialized since 1986, while 3D construction has been studied only since 2012, and there are still some problems, and the biggest technical obstacle is the 3D concrete material. The technical requirements of 3D printer for 3D concrete is to have the dual characteristics of pumped concrete and shotcrete, i.e., it has the mobility of pumped concrete in the printer, and it is like shotcrete after extruding the nozzle of the printer. After the printer nozzle, like shotcrete, immediately lose fluidity, stay in the specified position no longer move, and soon produce a certain degree of strength to withstand the pressure generated by continuing to print; at the same time, 3D concrete must also have the strength, durability and other performance indicators of ordinary concrete. In this sense, high-performance shotcrete is the closest to 3D concrete, so the development direction of shotcrete is 3D concrete. Many scholars have positioned the application of 3D concrete in the field of architectural 3D printing. For example, China Academy of Building Research, Hebei University of Technology, Shanghai Yingchuang Technology Co., Ltd. are committed to the research work of 3D printing building, and successfully used 3D technology to build some buildings, it can be said that the building 3D printing technology has made some progress, 3D printing building era or 3D printing building and traditional building, assembly building three-legged era called for [9].

The biggest advantage of 3D printing technology is to save manpower, and in terms of the many applications of concrete, the concrete construction of building projects is not the least efficient, therefore, we propose the "bow-shaped concrete support project 3D printing technology", which is the most important application field of 3D concrete, and also the most important development of sprayed concrete. direction.

"Bow-shaped concrete support project 3D printing technology" can also be called "bow-shaped concrete support project intelligent manufacturing technology", its main application areas in tunnels, culverts, subways, civil defense, coal mine tunnel, military engineering and other concrete support project fields. The main application areas are in the field of concrete support engineering such as tunnels, culverts, subways, civil defense, coal mine tunnel, military engineering, etc., which can better reflect the advancement of 3D printing technology, and can give full play to the advantages of 3D printing technology.

## **5. CONCLUSION**

Shotcrete technology is widely used and plays an important role in modern civil engineering construction, especially in tunnel construction, shotcrete support has become a necessary support measures, as civil engineers, we need to master shotcrete technology.

There are many factors affecting the performance of shotcrete, cement quality, aggregate gradation ratio, the quality and addition of quicklime, the proportion of shotcrete design, spraying machinery and the quality of spraying personnel will have an impact on the performance of shotcrete, improve the performance of concrete, the selection of materials, the optimal proportion design, improve spraying machinery, adding steel fibers, selecting high-quality quicklime, and improve the level of management. All can improve the performance of shotcrete.

Sprayed concrete is developing to high strength and high durability, which requires more and more requirements on the quality of admixtures and reasonable grading. Therefore, it is of great significance to study new type of admixtures and concrete proportion for shotcrete.

The development direction of shotcrete is 3D concrete, and its main application areas are 3D printing of construction and 3D printing of bow-shaped concrete support project.

## REFERENCES

- [1] Guan Baoshu. Sprayed Concrete Support Technology for Tunnels and Underground Works [M]. Beijing People's Transportation Press, 2004.
- [2] Cheng Liangkui. Sprayed concrete [M]. Beijing: China Construction Industry Press, 1990.
- [3] ZHANG Xiangdong, ZHANG Shuguang, LI Yongjing. Development and application of sprayed concrete technology [J]. Coal Science and Technology, 2000, 10(1):19-21.
- [4] Zhu Guangbing. Research progress of sprayed concrete [J]. Concrete, 2011(4):105-109.
- [5] LIU Fuzhang, ZHANG Zengjiang, LI Nuo. Research on technical performance of sprayed concrete [J]. Commercial Concrete, 2009(9):46-48.
- [6] GB/T 35159-2017, Quick-setting agent for sprayed concrete [S].
- [7] Xie Xingbao. Principle and characterization of modern shotcrete technology[J]. Journal of Wuhan University of Water Resources and Electric Power, 1994, 27(6):658-665.
- [8] Shi Yayong. Application of shotcrete in engineering [J]. Yangzhou Industrial Industry Vocational Technology, 2009, (11): 17-20.
- [9] J. Jiang, J. Ning, Y. Gao. JIANG Jianning, GAO Yuxin, WU Xiong et al. Discussion and analysis on the research status of concrete 3D printing technology [J]. Concrete, 2015(5):62-65.
- [10] XIAO XUWEN, TIAN WEI, MIAO DONGMEI. Application of 3D printing technology in the field of construction [J]. Construction Technology, 2015, 44(10):79-83.