A Review on the Geopolymer Materials Used in Grouting Piles

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Abstract. Bored cast-in-place piles are often used in power transmission projects. However, common bored cast-in-place piles with mud wall protection had some shortcomings, such as complicated construction procedure, poor quality of concrete, low bearing capacity, and pollution caused by mud wall protection. In this paper, the construction technology, quality evaluation method and design calculation of the new technology of Continuous Flight Auger pile were summarized. In addition, this technology combining geopolymer high strength concrete material was proposed, and the application of this technology in power transmission projects was prospected.

1. Introduction
Geopolymer referred to the cementitious material produced from natural mineral, solid waste and artificial aluminosilicate compound. Among them, the most widely used polymer is metakaolin in civil engineering from 80s of the last century. According to researches, 10%-15% of metakaolin replaces cement, which can increase concrete tensile strength by 1.3 times and compressive strength by 2.0 times. At the same time, the price of ordinary Portland cement is 300 yuan/tons to 400 yuan/tons, the price of metakaolin with 325 meshes is about 400 yuan/tons.

As the continuous development of China, the prices of infrastructure-related materials have continued to grow. At the same time, the uncontrollable costs such as construction site requisition and cleaning costs have risen rapidly. Under the above-mentioned multiple factors, the cost of civil engineering projects is rising, and the cost control and pollution reduction of civil engineering projects has become a hot spot. At present, the basic types of geotechnical engineering projects mainly include rock anchoring foundation, excavation foundation, large excavation foundation and bored pile foundation. Among them, the bored pile foundation has the advantages of convenient construction and good safety. If the local foundation bearing capacity does not meet the requirements, the boring foundation and the bored pile foundation should be preferred. However, the lubrication effect of mud skin and the cushion effect of bottom sediment make the pile bearing capacity low, construction efficiency low, mud pollution and other environmental shortcomings.

In order to overcome the above problems of ordinary bored piles, a long spiral grouting pile construction method (named as Continuous Flight Auger Piles) in the 90s of last century was proposed \cite{1, 2}. The process was summarized as following: (1) The drilling rig reached to the bottom of bored...
hole; (2) The fluidized concrete aggregates was pumped from the top of drilling device into the hole; (3) The drilling rig was lifted and the concrete pile formed; (4) After the concrete was poured into the designed level, the steel cage was inserted into the concrete pile by special vibration device [3]. Because there was no mud wall, few sediment existed at the bottom of the pile, which greatly increases the bearing capacity of the pile [4, 5]. However, there is no scientific method to evaluate the quality [6] and bearing capacity [7] at present.

This paper aims to summarize the research on construction technology, quality evaluation, calculation and geopolymer material characteristics of pressure-filled pile technology, and then the usability of geopolymer and auger-drilling pile-filling technology in civil engineering is look forward.

2. Geopolymer
The metakaolin is an intermediate product during the heat treatment of kaolin. The pozzolanic effect is actually the reaction process of the active SiO2 and Al2O3 oxides and the cement hydration product Ca(OH)2. Since the 1980s, the researchers found that the metakaolin can effectively improve concrete strength and corrosion resistance [8-15].

Previous researchers found that adding a certain amount of metakaolin can improve the early compressive strength of concrete based on a large number of laboratory tests [16-19]. It was also found that metakaolin can also increase the tensile strength and flexural strength of cement-based materials [20]. In addition, the corresponding bulk porosity and large pore volume of the block were greatly reduced [21], while the amount of cementitious hydration products and the energy released during the hydration of the concrete slurry are greatly increased. It can also improve the resistance and durability of concrete under erosion and freeze-thaw [22].

Qian and Li [19] used the MTS test to study the axial tensile strength of concrete with 0%, 5%, 10%, and 15% metakaolin. The results showed an insignificant influence on the fluidity of the concrete metakaolin. The 10% to 15% metakaolin can effectively increase the tensile strength and the toughness of concrete. The early compressive strength improvement was more significant. Deng et al. (2016) [23] used the unconfined compressive strength analysis to study the influence of metakaolin on the mechanical strength of cemented soil. The test results show that the unconfined resistance of cemented soil after the incorporation of geopolymer into cement soil has been greatly improved.

Through the above research, it is found that the metakaolin additive can effectively improve the tensile strength of concrete, and by blending with other additives, the reinforcement ratio can be further reduced, thereby reducing the cost of the pressure-filled pile and solving the problem of difficulty of inserting the reinforcement.

3. Steel Fiber
Steel fiber is a kind of recyclable material, which can be made from industrial waste and meet the requirements of energy conservation and emission reduction advocated by China. There are four kinds of common steel fibers on the market: copper plated microfilament type steel fiber, milling pin type steel fiber, end hook type steel fiber and melt drawn type steel fiber. These four kinds of steel fibers have different effects on the physical and mechanical properties of concrete as shown in figure 1.

Adding a certain proportion of steel fiber to concrete can not only improve its compressive strength, tensile strength, toughness and carbonation resistance, but also can be applied to many special engineering construction which can not be enhanced by steel bars. Many scholars have made research on this optimal amount of steel fiber. Single wave and other studies show that adding steel fiber can make the compressive performance and deformation of high-performance concrete The performance, direct shear performance and bending resistance are improved obviously, and the critical amount of reinforcement effect is 2%-3% [24]. Lu et al. [25] studied the influence of different fibers on the strength of ultra-high performance concrete, and found that the effect of adding steel fiber on the strength of concrete is obvious, the peak value of strength can reach 110 MPa in 28 days. The experimental results from Liu et al. [26] showed that the addition of steel fiber is significant on tension strengths. The results showed that the higher the basic strength of concrete was, the more obvious the
effect of steel fiber on splitting tensile strength was. In the range of length diameter ratio 40-80, the splitting tensile strength ratio of steel fiber reinforced concrete increases with the increase of steel fiber length diameter ratio. Zhang et al. [27] look forward on the applicable mathematical expression of the axial tensile stress-strain curve of SFHSC through the test, which can provide the theoretical basis for the design and analysis of SFHSC structure. Zhao et al. [28] showed that the flexural failure mode of SFHSC changed from brittleness to toughness, and the deformation capacity changed with the fiber volume Wu et al. [29] used different kinds of common steel fibers to test the slump and yield stress. The results showed that the milling pin steel fiber had little effect on the slump of concrete.

However, the addition of steel fiber in concrete will increase the conductivity of concrete, reduce the chloride ion penetration resistance and sulfate ion corrosion resistance of concrete itself. As the removal can also improve its carbonation resistance, it will not affect the durability basically. In terms of durability, steel fiber has an adverse effect on the resistance of concrete to chloride ion penetration, but it is conducive to improving the resistance of concrete to carbonation. The pressure pump test shows that adding a small amount of steel fiber has little effect on the structure of cement stone.

![Graph showing slump of concrete with different types of fibers](image1)

![Graph showing change of yield stress with different types of fibers](image2)

Figure 1. (a) slump of concrete (mm) with different types of fibers when fiber content is 0.5%; (b) slump of concrete (mm) with different types of fibers when fiber content is 1%; (c) slump of concrete (mm) with different types of fibers when fiber content is 1.5%; (d) change of yield stress (kPa) of fresh concrete with different types of fibers.

4. Superplasticizer

Water binder ratio is an important factor affecting the performance of MK-SF concrete. Within a certain range, the smaller the water binder ratio of concrete, the better the later performance of concrete. In order to reduce the water binder ratio of concrete, many scholars began to study the concrete water reducer, how to synthesize the water reducer with lower cost and higher efficiency, the best dosage of the new water reducer, and the original function of the water reducer. The theory has been studied deeply.

A new type of carboxyammonia superplasticizer was prepared based on experiments. It not only reduced the cost of traditional sulfamate superplasticizer, but also improved its performance. In
addition, the effects of additive B (active monomer B with sulfonic acid group) and urea on the properties of superplasticizer were further studied, and the best adding process and parameters of additive B and urea were obtained. The results showed that the cost of the superplasticizer could be further reduced by adding proper amount of additive B and urea, while improving the dispersibility of carboxyammonia superplasticizer [30]. A series of methods to characterize the superplasticizer for concrete. Through the measurement of surface tension, active substance content, adsorption capacity and ζ potential, the mechanism of the superplasticizer was studied from the microcosmic point of view, and the cause of slump loss was analyzed [31].

The concrete superplasticizer commonly used at home and abroad, and compared its performance. The action mechanism of superplasticizer for concrete is described, and its development trend is prospected [32]. It was summarized the latest research results. The results show that there are two main mechanisms of superplasticizer, namely, electrostatic repulsion theory and space potential resistance theory. The former is mainly suitable for naphthalene and melamine series superplasticizer, while the latter is suitable for the new type of superplasticizer which is in the development stage, including the main chain containing haloxyl and the side chain containing polyoxyethylene [33].

A polycarboxylate superplasticizer and studied the influence of initiator, chain transfer agent, monomer and other factors on the fluidity of cement paste, and analyzed the relationship between the concentration of different superplasticizer solutions and the surface tension. The research shows that when the initiator dosage is 5% of the monomer dosage, the chain transfer agent is 0.3%, SAS is 15%, and the mass ratio of MAA/MPEG is 8. The water reduction agent has good dispersibility and plasticity, and good adaptability to different cements [34]. Based on the discussion of the influencing factors of slump loss, the slump loss of concrete mixed with superplasticizer was greatly controlled by superplasticizer and the stages of adding superplasticizer [35].

Shi and He used the carbonation test, and got the conclusion that the carbonation depth value of the concrete with superplasticizer increased slowly in the early stage, and increased relatively quickly in the later stage. Adding superplasticizer can reduce the content of Ca (OH)₂ and to improve the early carbonation resistance of cement, and polycarboxylate superplasticizer can promote the cement hydration fully [36]. Zhao et al. Studied the influence of three kinds of superplasticizers (PCA, h-pns, l-pns) on the initial fluidity, compressive strength, carbonation, permeability diffusion coefficient of chloride ion, and the damage performance of dry wet cycle of concrete slurry. They found that PCA superplasticizer had lower mixing amount, better slump retention and earlier time than h-pns and l-pns superplasticizer It is characterized by rapid development of stage intensity [37].

Wei et al. Introduced the performance characteristics and mechanism of polycarboxylate superplasticizer, summarized the research status of polycarboxylate concrete superplasticizer at home and abroad, discussed the main problems of polycarboxylate superplasticizer, and proposed the research direction and content in the future [38]. Liu et al. reported the effect of sand content on the performance of polycarboxylate superplasticizer concrete through experiments. The experimental results show that when the sand content is less than 3%, it has little effect on the concrete strength, but the concrete slump decreases with the increase of mud content. When the silt content of sand is more than 3%, on this basis, for every 2% increase of silt content of sand, the concrete strength will be reduced by 5% and the admixture of water reducing agent will be increased by about 0.1%. Moreover, it was configured a kind of agent which can effectively inhibit the influence of silt content on the performance of concrete when mixed with polycarboxylic acid water reducing agent [39].

5. Construction Process
The long spiral drilling and pressing pile is a pile-forming technology developed on the basis of the long spiral dry drilling method. The principle of the process is: using a long auger to drill to the design elevation, using a concrete pump to push the concrete from the bottom of the drilling device. The drilling method is carried out into piles, and then the steel cage is inserted into the pile. Pile diameter is generally 400-800 mm, the drilling depth is 30 m, and the value of pile capacity is 1200-3000 kN. Compared with bored piles and pipe sinking compaction piles, the high pressure filling piles changes
with the stress state of the soil and the different construction processes. Due to the squeezing effect of the immersed pipe pile construction process, the effective stress of the soil changes the most, then the settlement of the pile is smallest under the same load. As shown in figure 2, the settlement of the bored pile is between the pipe sinking compacted pile and the bored pile.

Two different grouting piles were normally used: one is the continuous drilling and cast long spiral pile, mainly in the conventional rig continuous pore; one is drilling spiral piles (SPs) mainly made of drills with spiral wings, and the shape of the holes is spiral. After placing the steel cages, they are pressed into the concrete piles. The construction method of CFA pile and SPs pile is specifically shown in figure 2. During the construction of the CFA pile, the excavation of the soil uses a double-helical drill bit consisting of an upper large diameter enlarged head and a lower auger bit (figure 2a). When the depth of the excavation reached (figure 2a), the drill bit was lifted by 0.5 m. From the small hole in the center of the bottom of the drill bit (figure 2b), concrete or cement mortar is injected through the high pressure (figure 2c), and then the drill bit and the grouting pipe continue to be lifted to form the pile (figure 2b). When the drill bit is fully drilled, insert the bundled steel cage into the pile (figure 2c). In order to overcome the resistance caused by the insertion of the cage, it is usually sunk the cage by mechanical vibration (figure 2c). During the construction of the SP pile, a separate enlarged drill bit with thick flanges is usually used (figure 2b). If it is a cohesive soil, it is easy to form a spiral pile. If it is gravel or saturated sand, a collapse or diameter reduction will form. Finally, insert the small diameter casing and the steel cage, and inject the concrete or cement mortar with high pressure (figure 2c).

![Figure 2. The sketch of performing procedures of CFA piles and SPs piles.](image_url)

### 6. Conclusions

In summary, several conclusions can be drawn as:

1. From comparing with the construction processes, the long spiral drilling and pressure-filling pile does not require mud retaining wall, produce no mud pollution and sediment.

2. From comparing of pile quality, due to the large filling factor of the pile, the combination with the pile wall effectively improves the side friction resistance and the pull-out bearing capacity. From the calculation method, due to the short application time, there is no relevant mature calculation method.

3. From the point of view of the pile body material, the use of metakaolin combined with pressure irrigation technology can not only improve the tensile strength, compressive strength and durability, but also solve the shortcomings of difficult insertion of steel cages.

Therefore, the combination of geopolymer high-strength concrete material and spiral drilling and
pressure-filling pile technology has a good application prospect in civil engineering.

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