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# APPLICATION PROSPECT ANALYSIS OF HYBRID FIBER CONCRETE SUBWAY SHIELD SEGMENT

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**ABSTRACT**
With the rapid development of social economy, the urban population is increasing day by day, and the traffic pressure is increasing. Subway tunnels will be an inevitable trend to alleviate the pressure of urban rail transit. However, currently, the shield tunnel segments used in subway tunnel engineering mainly use ordinary reinforced concrete. The brittleness and low crack resistance of the material itself cause a large number of cracks and damage during the production, transportation, and construction of shield tunnel segments, directly affecting the safety and durability of subway tunnel engineering. In response to the many unfavorable factors of ordinary reinforced concrete subway shield tunnel segments, this article preliminarily explores the use of hybrid fiber concrete instead of ordinary reinforced concrete through various literature and on-site investigations. By utilizing hybrid fiber reinforced concrete which has a record of excellent performance, the various shortcomings of ordinary reinforced concrete subway shield tunnel segments can be compensated. The research results of this article provide an important basis for the development and production of hybrid fiber reinforced concrete subway shield tunnel segments.

**Keywords:**
*Subway shield tunnel segment; Fiber reinforced concrete; subway engineering*

## OVERVIEW

As an important component of the urban rapid rail transit system, the subway has gradually become the main force of urban public passenger transportation networks due to its characteristics of safety, speed, land conservation, low noise, low pollution, and energy conservation. In addition, this form of transportation is not affected by climate conditions. According to China Highway and Transportation magazine, the total length of urban rail transit in 50 cities in the Chinese Mainland will reach 9192.62 km in 2021, of which the subway will account for 78.9% (Yang Fengyuan, 2023).

With the development of the urban population and the increase of traffic pressure, the development of tunnel engineering will become an inevitable trend in urban underground rail transit. In the future, there will be more tunnel projects, indicating a rapid increase in demand for shield tunnel segments. The subway project is a century-old project, and it is necessary to study the key technologies of high-performance subway shield tunnel segments.

## RESEARCH QUESTION AND HYPOTHESIS

At present, the shield tunnel segments are mainly ordinary reinforced concrete segments with a diameter of 6 meters. Through on-site investigation and research, it was found that the weight of the 1.2-meter-wide A-shaped reinforced concrete pipe segment is about 4 tons. During transportation and installation, a large number of cracks and even damage may occur in the pipe segment. The cracking and damage of pipe segments will undoubtedly seriously affect the safety and durability of tunnel engineering. On the other hand, for underground engineering, the carbonization of the structure itself, the corrosion of external erosion, and the electrochemical corrosion of stray currents in the tunnel require the shield tunnel segments to have good durability. In addition, tunnel engineering is located in an underground environment, and its impermeability, corrosion resistance, and fire resistance will be important indicators of shield tunnel segments. These are problems that are difficult to overcome for ordinary reinforced concrete pipe segments.

Fiber reinforced concrete subway shield tunnel segment is a new type of composite segment that has received much attention and development in recent years. Compared with ordinary subway direct shield tunnel segments, it has better physical and mechanical properties. By replacing ordinary concrete with fiber reinforced concrete, the mechanical properties of subway shield tunnel segments, such as tensile strength, bending strength, wear resistance, impact resistance, fatigue resistance, toughness, and crack resistance will be improved. The durability is convenient, but it also has the advantage that ordinary reinforced concrete segments cannot be compared to. Its resistance to damage, permeability, carbonization, corrosion, and fire resistance will be significantly improved.

## DEFECTS OF ORDINARY REINFORCED CONCRETE SUBWAY SHIELD SEGMENTS

Prefabricated reinforced concrete pipe segments are the main lining structure of tunnel engineering, capable of withstanding underground soil and water pressures. At present, the overall trend in tunnel engineering design and construction is to gradually increase the diameter of the tunnel, which leads to an increase in the size of the lining blocks. The most direct problem is that large areas of cracks and damage often occur during production, transportation and installation, directly affecting the quality of tunnel engineering. Through on-site investigation and analysis of the failure pattern of the pipe section, cracks in ordinary reinforced concrete pipe sections mainly take the following forms:

### *1) Cracks on the outer arc of the segment*

This type of damage often occurs in two situations. The first is on the outer arc of the pipe segment after underwater repair, which belongs to the surface of fine cracks. Another type is surface cracks that appear after steam curing, which belong to concrete shrinkage cracks. The first type of crack is very common in the production process of tunnel segments and is also the most important fracture form of shield tunnel segments. It is only easy to see when the segments are damp. The second type of crack is caused by uneven surface temperature during the hydration process of large-volume concrete shield tunnel segments.

### *2) Side cracks of the segment*

The main reason for this type of crack is the carbonation shrinkage caused by the alternating temperature changes during the curing process of dry and wet concrete, which is a type of carbonation shrinkage crack. Although the carbonation of concrete, such as the carbonation of hydration products such as C-S-H gel, usually takes a long time, the carbonation of concrete surface can be completed in a short time or even several hours, plus the superposition of drying shrinkage, when the tensile strength of surface concrete is not enough to resist the tensile stress generated by shrinkage. It directly leads to the surface cracking of concrete, resulting in micro cracks (Zhang Yaodong and Yu Wei, 2018).

### *3) Cracks in the hand hole of the segment*

This kind of crack mainly occurs after the concrete is in the steam curing stage, where the main shape of the crack is eight, and is relatively thin and continuous. In general, the larger the hand hole, the more obvious the crack. The main reasons for its formation are, on the one hand, the concrete has a large self-shrinkage during the hydration process while on the other hand, the thermal expansion of the steel mold

produces a large temperature-concentrated stress. The superposition of the two results in a 45° direction of surface shrinkage crack.
The results show that the cracks of common reinforced concrete subway shield segments are mainly plastic shrinkage cracks. The main reason for the cracks is that the surface shrinkage cracks easily occur because of the large diameter, volume, thickness and arc of subway shield segments. From the perspective of the mechanism of crack generation, the main reason is that the shrinkage stress in the process of concrete curing is greater than the tensile strength of concrete.

Figure 1: Damage to ordinary reinforced concrete shield segment

In addition to the plastic shrinkage cracks generated in the production process, the ordinary reinforced concrete subway shield segments are often damaged during transportation and construction due to their large volume and heavy quality. The main forms of damage are as follows:

(1) Segment collapse: This refers to the segment edge damage caused by the uneven force of the shield on the pipe which may be caused by the careless transfer and installation of the segment and the improper attitude control of the shield machine.

(2) Segment misalignment: This refers to the damage caused by the unevenness between the two segments at the circumferential and longitudinal joints of the segment, the bad posture of the shield machine, the improper selection of segments, and the incomplete grouting behind the segment, and the careless installation, which is generally not easy to repair and can only be controlled during the driving process.

Cracks and damage of subway shield segments will cause the overall damage of subway lining structure, and then cause tunnel leakage and corrosion, which is a great challenge to the control of project quality and safety. According to the investigation of multi-city subways, the damage to ordinary reinforced concrete segments is mainly caused by excessive impact force and tensile stress (YAN Zhiguo, Zhu Hehua, Liao Shaoming, Liu Fengjun, 2016).

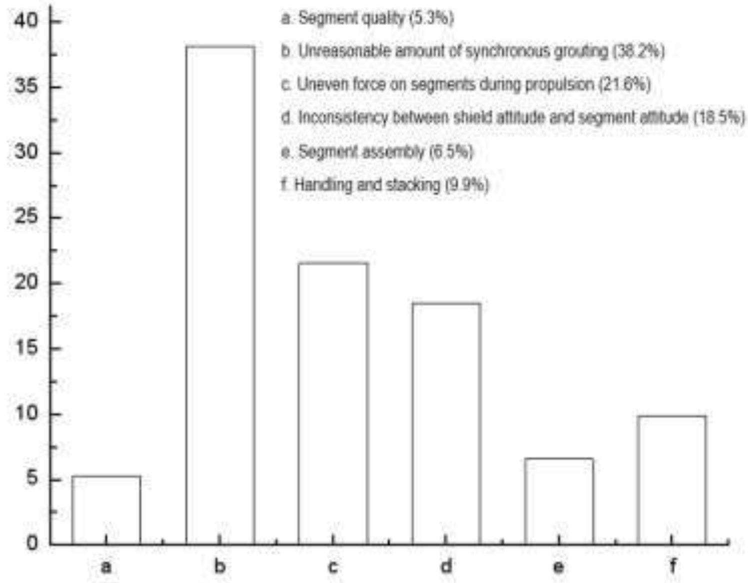


Figure 2: Schematic diagram of failure causes and proportion of ordinary reinforced concrete subway shield segments

In addition to cracks and damage, ordinary reinforced concrete subway shield segments are not ideal in terms of fire resistance and corrosion resistance. Fire resistance is an important index of tunnel engineering. Ordinary reinforced concrete segments do not consider the fire resistance factor. Fire resistance of tunnel engineering cannot be guaranteed; there are serious fire safety risks. In addition, because of its special engineering environment, the erosion of concrete structure is more complicated and severe than that of ordinary engineering. Subway projects are often located in strata with abundant groundwater and strong permeability, and the groundwater in China, especially the shallow groundwater, is seriously polluted and rich in corrosive media such as chloride ions and sulfate ions. Therefore, the subway shield segment, as a structure that has been immersed in groundwater for a long time, suffers from the dissolution of underground pressure water and the erosion of acidic groundwater. The groundwater contains sulfate, chloride ion erosion, etc.(Huang Wenxin , 2014)

## RESEARCH STATUS OF FIBER CONCRETE

As one of the most important composite materials in construction, concrete has good compressive strength and durability, and is widely used in housing, roads, bridges and other engineering construction fields. At present, China's annual consumption of coagulation, reaching more than 10 billion tons, is the highest utilization rate of building materials (Industry Publicity Department of China Concrete and Cement Products Association, 2023). However, it also has some shortcomings, including low tensile and bending strength, impact resistance, knock resistance and poor toughness, etc. These shortcomings seriously limit the full play of the advantages of concrete. With the improvement of concrete strength, these shortcomings are also more prominent. As we all know, the higher the strength of concrete, the more negative its toughness, brittleness, crack resistance and structural ductility. Structural seismic performance and fire resistance will also be correspondingly reduced, and the durability of concrete structure will be more prominent ( Han Dachun, 2010). Methods and approaches to improve the above properties of concrete have been constantly explored by many scholars for a long time, among which fiber-reinforced concrete is one of the most widely studied and applied important approaches in recent years (Wang Zhengyou, 2002). At present, there are two main types of fiber reinforced concrete. The first is high elastic modulus short fiber reinforced concrete, which is represented by steel fiber. The second is the short fiber reinforced concrete with low elastic modulus, which is represented by polypropylene fiber and nylon fiber (He L J. , 2007).

Fiber concrete is a cement-based composite material composed of cement slurry, mortar or concrete as the base material and metal materials, inorganic materials or organic fibers as the reinforcement material. It is a new building material formed by mixing short and fine fibers with good properties such as high tensile strength, high limit elongation and high alkali resistance into the concrete matrix. By adding fiber materials to the matrix concrete, the development of plastic cracks in the early stage of the matrix concrete can be inhibited, the expansion of cracks in the matrix material under external load can be hindered, the degree of dry shrinkage and cold shrinkage can be reduced, and the properties of tensile, bending, explosion, impact and toughness of the matrix concrete can be greatly improved. And it will promote the durability of concrete impermeability, frost resistance, waterproofing and other great progress.

Fiber concrete first appeared in the early 20th century, with the earliest and most extensive research being on the application of steel fiber concrete. Russian experts applied steel fiber to concrete, beginning the development history of steel fiber concrete. In the United States, HP Porter added steel fibers to ordinary concrete and published the first research report on staple fibers. He proposed the uniform dispersion of staple fibers in concrete as a strengthening structural material. Granham, also from the United States added steel fiber to ordinary reinforced concrete and came to the conclusion that adding steel fiber could improve the strength and volume stability of concrete. American scholars J.P. Roomualdi and G.B. Busson published a series of research papers on the crack resistance mechanism of steel fibers, and developed the theory that the cracking strength of steel fiber concrete is determined by the average distance between steel fibers that plays an effective role in tensile stress. This is the famous "fiber distance theory". It opens a new era of practical research of fiber-reinforced concrete (Cox, H. L.,1952).

In the United States, fiber reinforced prefabricated wall panels, balconies, corrugated panels and hollow floors have been widely used in high-rise buildings, and a large number of highway pavements and bridge decks have been laid. A typical example is the surfacing project of the tank parking lot in Fort Hood, Texas, where steel fiber concrete is used as the cladding material, and the service life is increased by nearly eight times. The fiber concrete doped with fly ash was adopted at the Denver International Airport, which significantly reduced pavement thickness and saved a lot of investment (Chen Liang, 2006). In Canada, the Lafarge Cement Applied Research Center and the Industrial Materials Research Institute collaborated to establish the largest private fiber concrete laboratory in North America in 1985 to test the steel fiber concrete pavement. The test shows that the pavement thickness can be reduced by 20% when reinforced with glass fiber and 45% when reinforced with steel fiber (Rong Jianlin , 2006).

A research group (R.N.Swamyete, 1981) from the University of Sheffield in the United Kingdom has carried out research on the basic theory of fiber reinforced coagulation and engineering practical problems in design and construction, and achieved a series of results. Steel fiber-reinforced concrete has been successfully applied to prefabricated flooring in the high-rise parking lot of London Heathrow Airport, the runway and apron modification project of Frankfurt International Airport, and a Swedish rock stabilization and structural reinforcement project. In Europe, the most widely use for steel fiber-reinforced concrete is flooring and wall panels in industrial buildings, as well as pavement paving, followed by tunnel linings and various prefabricated building components (Morton, J.1997). In Japan, starting from 1973, companies have carried out research and development work of steel fiber concrete, and promoted the application of building structures, tunnel linings (such as the central highway Huinayama tunnel), road paving, airport runways, bridge decks and structural local reinforcement.

Since the 1970s, nylon, polypropylene, plant and other low-elastic fiber concrete and carbon, glass, asbestos and other high-elastic fiber concrete have also attracted the attention of scholars around the world with the development of steel fiber coagulants. Especially in Europe, Japan and the United

States, synthetic fiber concrete has been more widely studied and applied, and there are many examples for new construction and repair projects. In the United States, the amount of synthetic fiber concrete has accounted for 7% of the total output of concrete, which is far more than the previously developed steel fiber concrete (3%), and is regarded as a new development of modern concrete technology (Duan Fuqiang, 2017).

In view of the excellent properties of steel fiber concrete and polypropylene fiber concrete respectively, Kobayashi K et al. studied the bending properties of steel fiber - polypropylene fiber hybrid fiber concrete. The term "hybrid" first appeared in academic papers on fiber concrete, and since then, the research on hybrid fiber concrete has gradually increased. Later, Glavind and Aarre et al. showed that steel-polypropylene fiber concrete could increase the ultimate compressive strain of concrete.

Chinese research institutions have also done a lot of experiments in the field of fiber concrete, Professor Yao Wu et al. conducted experiments to study the effect of mixing carbon-steel fiber, carbon-polypropylene fiber and steel-polypropylene fiber on the mechanical properties of high-performance concrete at low content (the total fiber volume content of 0.5%), respectively. The three types of mixed fibers can all improve the compressive strength and elastic modulus of concrete. Qian Hongping et al. studied the effect of fiber hybrid (high-elastic modulus steel fiber, high-elastic polyvinyl fiber, and low-elastic modulus polypropylene fiber) on concrete shrinkage performance at various ages: whether it is a single fiber or mixed among fibers, the shrinkage rate of concrete can be significantly reduced, but the effect of fiber hybrid is significantly better than that of single fiber.

Huayuan et al. studied the bending fatigue properties of carbon fiber-polypropylene fiber concrete. The law of fatigue life and fatigue strength changing with the mixture amount of hybrid fiber is obtained as well as the fatigue equation of materials. The characteristics of fatigue residual strain accumulation, cyclic strain amplitude evolution and total fatigue strain amplitude development of hybrid fiber-reinforced concrete under high-frequency cyclic load are discussed, and a flexural fatigue deformation model of hybrid fiber-reinforced concrete material is established. Deng Zongcai et al. tested the bending fatigue characteristics of hybrid components of steel fiber and cellulose fiber, and found that hybrid fiber can give full play to the advantages of various fibers, and has a significant effect on improving fatigue properties than single-doped steel fiber and cellulose fiber.

Academician Sun Wei et al. systematically studied the effects of the mixing of steel fiber and polypropylene fiber of different scales on the physical properties of cement-based materials, and found that hybrid fiber significantly improved the permeability resistance of concrete, and the more dimensional layers of hybrid fiber, the better the permeability resistance. Wang Hongxi et al. also showed that the impermeability of concrete gradually improved with the increase of the total volume and content of fiber. Sun Jiaying's test found that only when the fibers were mixed in a certain proportion, the permeability resistance of hybrid fiber coagulants was better than that of benchmark concrete [24]. Yang Chengjiao et al. studied the impervious properties of hybrid fiber (steel fiber - polypropylene fiber) coagulation through experiments and found that the impervious properties of concrete were little affected by hybrid fiber, but the addition of air-entraining agent could improve the impervious properties of hybrid fiber concrete.

Ma Xiaohua conducted a freeze-thaw test on hybrid fiber high-performance concrete to study the effect of hybrid fiber on the freeze-thaw resistance of concrete. The study found that after 200 freeze-thaw cycles, the loss of compressive strength and splitting tensile strength of fiber coagulation is smaller than that of plain concrete; At the same time, after the freeze-thaw cycle, the toughness of fiber high performance concrete will decrease, but the toughness loss of single fiber concrete is greater than that of hybrid fiber concrete. The durability test of concrete by Huayuan et al. also shows that the freeze-thaw resistance of hybrid fiber concrete is better than that of benchmark concrete. Based on the existing mathematical model of concrete carbonation depth, Dong Yanwei et al. proposed a calculation model of hybrid fiber concrete carbonation depth through carbonation test. The compressive strength of benchmark concrete and different hybrid types of concrete after carbonization is basically the same with the change in trend of carbonation age, and basically increases with the growth of age.

Dong Xiangjun et al. found that the addition of steel fiber could not inhibit the burst of HPC under fire, and the burst degree increased with the increase of steel fiber content. However, polypropylene fiber can effectively improve the fire burst resistance of high performance concrete. The mechanical properties of high-performance concrete after fire are mainly played by steel fiber, while polypropylene has little effect on the properties after fire. Therefore, the hybrid method of polypropylene fiber and steel fiber can complement each other, and at the same time improve the fire knock resistance and mechanical properties of HPC after fire. He Lijuan also obtained the above similar conclusion through experiments, and the addition of hybrid fibers improved the compressive shear failure criterion value of concrete after high temperature. When steel fiber mixed with a content of 35kg/m$^3$ and polypropylene fiber mixed with a content of 2.5kg/m$^3$, the compressive shear failure strength value increased by 27.6% compared with that of reinforced concrete.

## SIGNIFICANCE OF HYBRID FIBER CONCRETE APPLIED TO SUBWAY SHIELD SEGMENTS

Hybrid fiber-reinforced concrete (HFRC) is a new type of composite building material with excellent physical and mechanical properties. Compared with ordinary concrete, its tensile strength, flexural strength, wear resistance, impact resistance, corrosion resistance, fatigue resistance, crack resistance, explosion resistance and other properties are significantly more superior. The outstanding crack resistance and deformation resistance of mixed fiber-reinforced concrete can greatly reduce the crack width of components under the same load, greatly compensating for the shortcomings of ordinary reinforced concrete. At the same time, mixed fiber-reinforced concrete has good fire resistance performance, which can effectively solve the fire resistance requirements of special projects such as tunnel engineering; In addition, mixed fiber-reinforced concrete has excellent corrosion resistance and is fully adapted to the severe corrosive environment of underground engineering (Ning B. 2019).

Considering the defects of ordinary reinforced concrete shield tunnel segments, replacing ordinary concrete with mixed fiber concrete is undoubtedly an effective way to improve the safety and durability of tunnel engineering. By mixing high elastic modulus steel fibers with low elastic modulus polypropylene fibers, some or all of the steel bars in ordinary tunnel segments can be replaced, which also makes the mixed fiber subway shield tunnel segments better in terms of economic benefits. The main technical and economic advantages of mixed fiber concrete subway shield tunnel segments are as follows:

(1) It has better mechanical properties in terms of tensile, bending, and shear strength.

(2) It can effectively reduce plastic shrinkage cracks during the production process of pipe segments.

(3) It improves the required damage resistance of pipe segments during transportation and stacking processes.

(4) It improves the corrosion resistance of the shielding section;

(5) It is effective in improving the fire resistance of subway shield tunneling pipes to ensure the fire resistance of subway projects.

(6) It saves production costs, partially or even completely replacing steel bars, which undoubtedly greatly reduces the cost of pipe segments;

(7) It reduces the loss of steel molds, and partially or completely avoids the use of steel cages, improving the industrial production speed of segmented production, with output to possibly be more than doubled;

(8) It saves maintenance costs in the later stage due to its excellent performance, which greatly reduces damage to the pipe segments during engineering use;

In short, mixed fiber concrete has excellent performance and can fully compensate for the shortcomings of ordinary reinforced concrete subway shield tunnel segments.

**APPLICATION STATUS OF HYBRID FIBERS IN SUBWAY SHIELD SEGMENTS**

Concrete has become the largest and most widely used building material in construction engineering due to its high strength, good plasticity, and simple material source. However, it also has some drawbacks, including low tensile and bending strength, as well as poor impact resistance, blast resistance, and toughness. These shortcomings seriously limit the full utilization of the advantages of concrete, and as the strength of concrete increases, these shortcomings become more prominent. As is well known, the higher the strength of concrete, the poorer its toughness, brittleness, crack resistance, and structural ductility. The seismic and fire resistance performance of the structure will correspondingly decrease, and the durability of concrete structures will be more prominent (Chen Liang. 2006). For a long time, many scholars have been exploring methods and approaches to improve the above-mentioned properties of concrete, among which fiber-reinforced concrete is one of the most widely studied and applied important approaches in recent years (Halderen MWAM.1997). At present, there are two main types of fiber-reinforced concrete. The first is high elastic modulus short fiber-reinforced concrete, which is represented by steel fibers, The second, is the low elastic modulus short fiber concrete, which is represented by polypropylene fibers and nylon fibers (PU Ao. 2017).

With the deepening of research on fiber-reinforced concrete by various scholars, the achievements accumulated in the application process of fiber-reinforced concrete materials over the years, and the various drawbacks exposed by ordinary reinforced concrete in engineering practice, fiber-reinforced concrete has become an inevitable trend to replace ordinary reinforced concrete in important engineering projects. Although the application of fiber-reinforced concrete in domestic tunnel engineering is still in the experimental research stage, fiber-reinforced concrete has been widely used in tunnel engineering, especially in European countries where the technology of fiber-reinforced concrete subway shield tunnel segments has become quite mature.

With the continuous exposure of defects in ordinary reinforced concrete shield tunnel segments, many Western countries have begun to study the application of fiber-reinforced concrete in subway shield tunnel segments. Many countries have gradually started to use steel fiber-reinforced concrete instead of ordinary reinforced concrete in tunnel engineering. In European countries, the application technology of fiber-reinforced concrete pipe segments is becoming increasingly mature. Attempts to use mixed fiber-reinforced concrete prefabricated pipe segments in tunnel engineering projects include:

Section 34 of the German Essen Metro North Line (started in 1997): A 100-meter-long test line was constructed using prefabricated fiber-reinforced concrete on the Essen Metro North Line.

The "Second Heienoed Tunnel" of the Dutch highway tunnel (started in 1998): In the Netherlands, a 16-ring test tunnel was constructed using mixed fiber concrete segments in the "First Heienoed Tunnel" of the highway tunnel.

The "Trasvates Manabi" water conveyance tunnel project in Ecuador (started in 2000): In South America, Ecuador used mixed fiber concrete prefabricated pipe segments in the "Trasvates Manabi" water conveyance tunnel project, which is 11.4km long and has a diameter of 4m.

Barcelona Metro Line 9 (2009-2016) in Spain: A fiber concrete shield tunnel section was used in the construction of the Barcelona Metro Line 9. This project includes the installation of a tunnel lining composed of fiber-reinforced concrete.

Delhi Metro, India (Phase III, started in 2011): The expansion project of the Delhi Metro Phase III adopts a fiber-reinforced concrete shield tunnel section. The project is still ongoing, including the construction of a fiber-reinforced concrete section of a subway tunnel.

Türkiye Istanbul Metro (several lines, operating since 1989): Istanbul Metro and several lines have used fiber concrete shield sections in the construction of metro tunnels. The project began in 1989 and continued to expand, using fiber-reinforced concrete segments in tunnel lining.

The construction of Metro Line 5 in S ã o Paulo, Brazil (2004-2018) involves the use of fiber-reinforced concrete shield tunneling sections. This project was carried out from 2004 to 2018, using fiber-reinforced concrete sections for subway tunnel construction.

In China, the main engineering applications include the construction of a 50-meter steel fiber-reinforced concrete segment test section on the M6 line of the Shanghai Metro. Through various tunnel safety monitoring systems, real-time data (deformation and stress) of the segments during construction and operation are collected, and the advantages of steel fiber segments are systematically analyzed. The monitoring data shows that the experimental section is in good working condition and safe and reliable. The construction of Nanjing Metro Line 4 adopts fiber-reinforced concrete shield tunnel segments, which lasted from 2006 to 2012. The tunnel lining is composed of fiber-reinforced concrete segments. The shield tunneling section between Beitucheng Station and Shaoyaoju Station on Beijing Metro Line 10 has also attempted to apply steel fiber-reinforced concrete pipe segment technology. Engineering practice has shown that cracking is rarely found in the steel fiber-reinforced concrete section during transportation and installation, reducing a significant amount of maintenance costs in the later stage.

## DISCUSSION AND CONCLUSION

From the trend of urban development, it can be seen that tunnel engineering is an inevitable trend in the development of urban rail transit. From the many drawbacks of ordinary reinforced concrete subway shield tunnel segments, it can be seen that using mixed fiber concrete instead of ordinary reinforced concrete to make subway shield tunnel segments can significantly improve the mechanical properties, durability, and economy of the segments. At present, the application research of fiber-reinforced concrete in subway shield tunnel segments is not yet mature; the research on the application of mixed fiber-reinforced concrete in shield tunnel segments is just beginning. In addition, the production and research of subway shield tunnel segments are also in their infancy, so further research on the application of mixed fiber concrete in subway shield tunnel segments will have good scientific research and industrial prospects.

## AUTHOR BIOGRAPHY

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