Application of Glass Fiber Concrete under Thin-Walled Middle Partition Wall Construction in Tunnel

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Abstract. Aiming at the feasibility of applying glass fiber concrete as a new material to tunnel engineering, with the help of a combination of theoretical analysis, laboratory tests and engineering applications, the effect of glass fiber on the mechanical properties of concrete under different dosages and different lengths is studied. By monitoring the cracks in the middle partition wall, and applying the glass fiber to the middle partition wall in Laoshan Tunnel, to achieve the verification of the optimal length and the optimal mixing amount. The main conclusions are: (1) When the length of glass fiber is 12 mm, the tensile and compressive strength reach the maximum value; (2) Determine the optimal volume rate is 1% in order to prevent the concrete cracking effectively; (3) The crack resistance of the mid-board with glass fiber concrete is better than the ordinary concrete, which proves the feasibility of practical application of glass fiber concrete.
1. Introduction
In order to solve the problems of material self-weight, high brittleness, low tensile strength, poor crack resistance, and cracks on the concrete, the requirements for the use of concrete in engineering increasingly, and the new type of glass fiber can reduce the fracture of the slotted; the deformation performance is significantly improved. Therefore, it is extremely necessary to study the feasibility of using glass fiber concrete as a new material in tunnel engineering.

Kizilkanat A B, Khan M, Ali M [1-2] etc. found that the incorporation of glass fiber greatly improved the crack resistance and ductility of concrete through experiments. Song W, Yang S [3-4] and other studies have shown that the decrease of glass particle size in glass concrete will increase the strength of glass concrete. Wang W C, Hanuma K, Rao C B K [5-6] and others proposed that the proper addition of glass fiber can increase the strength of concrete and improve the crack resistance and toughness. Guzlena S, Sakale G [7] research highlights that PGRC has higher LOP and MOR values than GRC. Eiras J N, Deng Zongcai, Shen Wu [8-11] et al. found that glass fiber can improve the flexural tensile strength and bending performance of concrete significantly.

There are relatively few researches on the application of glass fiber concrete in tunnel engineering at domestic and overseas. Many scholars have studied its mechanical properties, but there are gaps in the mechanical properties of different engineering applications. The rigor of the results cannot be guaranteed by similar research methods. Therefore, this article analyzes the application of glass fiber concrete in tunnel engineering in order to fill the vacancy in this area.

2. The mechanism of action of glass fiber
2.1. Mechanics theory of composite material
The composite material mechanics theory used is based on the mixing principle of general composite materials, which is generally applied to composite materials of matrix materials and uninterrupted glass fibers in a single direction [12]. The settings of the model as follows:

1) The state of each fiber arrangement is parallel and continuous, and it forces in the same direction as the material.

2) The bond between the fiber and matrix is well and the strain is the same, \( \varepsilon_c = \varepsilon_m = \varepsilon_f \), without relative slippage.

3) The transverse deformation between the fiber and the matrix material is the same, and it is a linear elastic material.

Satisfying the above three assumptions and according to the following figure 1, it can be concluded that the force acting on the composite material, matrix, and fiber is:

\[
\begin{align*}
    f_c &= \sigma_c A_c \\
    f_m &= \sigma_m A_m \\
    f_f &= \sigma_f A_f
\end{align*}
\]  

Where: \( A \) cross section, \( \sigma \) stress, and small scale: \( c \) composite material, \( m \) matrix, \( f \) fiber.

![Figure 1. Schematic diagram of the mechanical action of fiber concrete composite materials.](image-url)
Substitute formula (1) into the balance equation:

\[ f_c = f_f \rho_f + f_m \rho_m = f_f \rho_f + f_m (1 - \rho_f) \]  

(2)

\[ \sigma_c = \eta_f \sigma_f \rho_f + \rho_m \sigma_m = \eta_f \sigma_f \rho_f + \sigma_m (1 - \rho_f) \]  

(3)

\[ E_c = \eta_f E_f \rho_f + \rho_m E_m = \eta_f E_f \rho_f + E_m (1 - \rho_f) \]  

(4)

Where: \( \sigma_c \) is the tensile strength; \( \rho_m = A_m / A_c \) is the matrix volume ratio; \( \rho_f = A_f / A_c \) is the fiber volume ratio; \( E_c \) is the elastic modulus of the fiber composite material with random distribution.

From the above calculation formula, the elastic modulus produced by the composite material is proportional to the volume content of the added fiber. Although \( \eta_f \) this coefficient is less than 1, as far as composite materials are concerned, since the elastic modulus and strength produced by glass fiber are much larger than that of concrete matrix, it is concluded that glass fiber has a very obvious effect on increasing the strength of concrete.

2.2. Theory of fiber spacing

The study of fracture mechanics has laid a solid foundation for the analysis of fiber spacing. The main reason for the failure of concrete is that it is exposed to a large external load, which results in pores and cracks of different lengths in the concrete, which can also cause stress concentration. As the cracks continue to extend, the concrete is destroyed. Figure 2 is a mechanical model of fiber spacing established by research. When the order of fiber placement for increasing concrete strength is clockwise, the fibers are set in the direction that generates tension and are evenly arranged in the matrix, assuming that the half-width of the concrete crack is \( a \), fiber the distance is \( S \), when the external load is tensile stress, the bond stress \( \tau \) distribution graph shown in Figure 2 will be produced at the fiber interface where concrete cracks are about to appear.

![Figure 2. Mechanical model of fiber spacing.](image)

According to Figure 2, it can be seen that the direction of the generated bond stress \( \tau \) is opposite to the force at the end of the concrete crack, which can reduce the stress concentration at the end of the concrete crack. This also shows that the fiber has the ability to inhibit the extension of the concrete crack. In this process, a strength factor opposite to the stress at the end of the concrete crack appear.
2.3. **The crack resistance principle of glass fiber on concrete**

Wang W C, Hanuma K, Rao CBK [5-6] and others proposed that the proper addition of glass fiber can increase the strength of concrete and improve the crack resistance and toughness. The strength of glass fiber is much greater than that of concrete, and another advantage is that it is small, which can have a good effect on the redistribution of cracks and stress in concrete. The principle of crack resistance on concrete has three stages:

1. Suppress the germination of original microcracks.
2. Prevent the growth of microcracks, as shown in Figure 3.
3. Enhance the toughness of concrete.

![Figure 3. Schematic diagram of the effect of glass fiber on stress concentration.](image)

According to Figure 3, if stress concentration occurs at the end of the concrete crack, this can make the concrete crack suddenly become larger, reducing the bearing capacity of the concrete, and continuing to be subjected to the load will cause the concrete to rapidly destroy, which will lead to the tensile strength of concrete is not fully functional. Glass fiber will produce a good crack resistance effect. Mixing glass fibers with different proportions into concrete can slow down the crack propagation speed of concrete and can reduce The crack-resisting effect of the concrete is maximized, especially the adding glass fiber to the end where the concrete cracks.

3. **Test analysis**

The performance of concrete is mainly reflected in the ability of tensile, compressive and crack resistance. Because these three properties of concrete allow concrete to have a wide range of applications, glass fiber can have good adhesion with concrete and can be well reinforced the tensile and compressive properties of concrete. This article mainly conducts the compressive and tensile tests of glass fiber concrete with different dosages and different lengths by indoor experiments, combined with the analysis of the reinforcement mechanism of fiber to concrete, and further discuss and analyze the test results.

3.1. **Compressive strength test-influence of fiber content**

In order to study the influence of fiber content on the compressive strength of concrete, two types of glass fibers (Cem-FIL60 12mm, HP12 mm) were mixed into the concrete matrix, and two strength grades (C35, C50) of concrete were used as the research. For the object, two different types of glass fibers with a length of 12 mm were selected to compare the effects of glass fibers on the compressive strength of concrete under different dosages. The specific test data are shown in Figure 4 and Figure 5.
**Figure 4.** Compressive strength and its improvement rate curve under C35 strength grade.

**Figure 5.** Compressive strength and its improvement rate curve under C50 strength grade.
It can be seen from Figure 4 and Figure 5, by comparing the different levels of the same color in the histogram in the figure, it can be concluded that when the glass fiber blending amount increases from 0.0% to 1.5%, with the increase of the amount, the compressive strength of concrete under different strength grades shows a trend of first increasing and then decreasing with ignoring errors. The obvious degree of the change rate shown by the graph curve provides a theory for studying the optimal amount of glass fiber. And is basically consistent with the change trend of Kizilkanat AB, Khan M, Ali M [1-2] and other research results. In summary: when the volume ratio of glass fiber is 1%, the compressive strength of concrete reaches the optimal value, and the compressive strength of concrete will not increase with the increase of glass fiber addition. The reason for this phenomenon is that when the too much amount of glass fiber is added, the glass fiber will condense together, so that the glass fiber is not fully utilized. In order to make the glass fiber play the maximum role, the amount of glass fiber added is determined to be 1%.

3.2. Compressive strength test-the effect of fiber length
Based on the research results of Song W, Yang S [3-4], etc., to explore the influence of glass fiber on the compressive strength of concrete under different lengths, three different lengths (Cem-FIL60 12 mm, Cem- FIL60 18 mm, HD6 mm, HP12 mm) glass fiber, two strength grades (C35, C50) concrete are selected as the research object, and glass fiber with a volume content of 1% is selected. The specific test is shown in Figure 6.

![Figure 6. The compressive strength of concrete with different lengths under different strength grades.](image)

It can be seen from Figure 6 that adding different lengths of glass fiber to C35 (red, yellow) and C50 (blue, green) concrete, both show the same trend of compressive strength changes. Observe the same vertical color in the figure: Both increase first and then decrease with the increase of glass fiber length. The compressive strength of concrete with glass fiber is obviously greater than that without addition. Therefore, it is not that the longer the length of glass fiber, the greater the effect on concrete. The length of glass fiber used in practical engineering is 12 mm commonly.
3.3. Tensile strength test—Influence of fiber length

Because the research of Eiras JN, Deng Zongcai, Shen Wu [8-11] and others have laid a theoretical foundation for the analysis of the influence of glass fiber on the tensile strength of concrete under different lengths, the results show that glass fiber can significantly improve the bending and tensile strength of concrete. Therefore, this section uses glass fiber concrete with a volume ratio of 1% model C30 as the research object, and compares and analyzes three kinds of glass with different lengths (Cem-FIL60 12 mm, Cem-FIL60 18 mm, HD 6 mm, HP12 mm) the stress-strain curves of the fiber cured for 7 days and 28 days under standard conditions are shown in Figure 7.

![Figure 7](image)

**Figure 7.** (a) (b) Tensile stress-strain curves of different glass fiber lengths.
It can be seen from Figure 7 that compared with ordinary concrete, glass fiber concrete has higher peak strength and residual strength after cracking. When the two kinds of concrete produce the same strain, the ordinary concrete must have a higher stress. The specimen is cured under standard conditions for 7 days. When the glass fiber of C12, HP12, C18, HD6 is added to the concrete, the strength of concrete has increased by 0.18 MPa, 0.16 MPa, 0.17 MPa, and 0.15 MPa respectively; when the concrete is cured under standard conditions for 28 days, the peak strength of the concrete will also increase. Based on the research conclusion of the length of glass fiber on the stress-strain curve of concrete under tension, the effect of the length of glass fiber on the tensile strength of concrete was quantitatively analyzed. The obtained results are shown in Table 1.

Table 1. The tensile strength values of C30 glass fiber concrete under different lengths.

| Model           | 7d Tensile strength /MPa | 28d Tensile strength /MPa |
|-----------------|---------------------------|---------------------------|
| HD-6mm          | 2.06                      | 3.04                      |
| HP-12mm         | 2.18                      | 3.08                      |
| Cem-FIL60-12 mm | 2.12                      | 3.06                      |
| Cem-FIL60-18 mm | 2.04                      | 2.96                      |

It can be seen from Table 1: As the length of the glass fiber increases, the maximum strength increase value first increases and then decreases. When the error factor is not considered, the length of the glass fiber is 12 mm, the maximum strength of the glass fiber is biggest, if the length of the glass fiber is too short in the process of tensile fracture, and the crack resistance of the glass fiber will be insufficient. When the length of the glass fiber is too long, the glass fiber will form agglomeration when mixing the concrete, making the glass fiber cannot play a role fully.

3.4. Tensile strength test-the influence of fiber content
In order to facilitate the analysis of the different degree of influence of different fiber volume ratios on the tensile strength of concrete, glass fiber concrete with a length of 12mm in model C30 is used as the research object, and the two models (HD12mm, HP12mm) under the volume content of 0%, 0.5 %, 1%, 1.5% were compared and analyzed, the specific test results are shown in Table 2.

Table 2. The tensile strength value of glass fiber concrete under different mixing amount of C30.

| Numbering | Incorporation amount /% | Project | 7d Tensile strength/MPa | 7d Rate of change | 28dTensile strength/MPa | 28d Rate of change |
|-----------|--------------------------|---------|-------------------------|-------------------|-------------------------|-------------------|
| HP JZ30   | 0                        |         | 1.74                    | 1                 | 2.69                    | 1                 |
| Test block 1 | 0.5                    |         | 2.15                    | 1.236             | 2.91                    | 1.082             |
| Test block 2 | 1.0                    |         | 2.25                    | 1.293             | 3.09                    | 1.149             |
| Test block 3 | 1.5                    |         | 2.20                    | 1.264             | 3.05                    | 1.134             |
| HP JZ30   | 0                        |         | 1.74                    | 1                 | 2.69                    | 1                 |
| Test block 4 | 0.5                    |         | 2.02                    | 1.161             | 2.86                    | 1.063             |
| HD JZ30   | 0                        |         | 1.74                    | 1                 | 2.69                    | 1                 |
| Test block 5 | 1.0                    |         | 2.18                    | 1.253             | 3.00                    | 1.115             |
| Test block 6 | 1.5                    |         | 2.12                    | 1.218             | 2.89                    | 1.074             |
According to Table 2: By comparing the tensile strength values of the two types of concrete test blocks with different volumes in the standard curing for 7 days and 28 days, the results show that the tensile strength of the concrete with glass fiber is significantly greater than that of the reference concrete, but with the continuous increase of fiber volume rate, its tensile strength keeps changing. It increases in the range of 0%~1% by volume and decreases in the range of 1%~2%. There is an optimal fiber volume rate in this range it can maximize the tensile strength of concrete, when the volumetric content reaches 1%.

4. Engineering Applications

4.1. Project Overview
The Laoshan Tunnel is a tunnel project between Beijiushui Station and Wanggezhuang Station. It is an important part of urban traffic, the length of the tunnel reaches 4580m. Its structure is a double-track single tunnel. The new Austrian tunnel method is adopted for tunnel lining. The construction of the tunnel, and the structure of the lining is composite, the tunnel construction adopts the construction method of drilling and blasting. The partition wall of the Laoshan Tunnel runs through from one end of the tunnel to the other end of the tunnel. The base wall is 0.3m thick and the height is 0.3m. The steel bars used are \( \phi18 \) in the horizontal and \( \phi14 \) in the longitudinal direction. The spacing of the steel bars is 20cm. The stirrup is \( \phi8 \), the design thickness of the steel protection layer is 5cm, and the final concrete model used is C30. The height of the standard section is 6.73m, and the highest point is 7.6m. The height of the whole section fluctuates steadily.

4.2. Glass fiber concrete construction process

Refer to Figure 8 for the construction process of glass fiber concrete in the partition wall of the tunnel. In the practical application of glass fiber concrete, a quantitative and timed mixing method is required for the mixing process, which can avoid large amounts errors during the mixing process.

Determine the type and length of the glass fiber in combination with the different test schemes in the previous article, and determine the volume rate of the glass fiber added each time according to the mixing amount of the on-site concrete mixing machine. Since the better crack resistance of glass fiber, the Glass fiber concrete was used in the Qingdao Blue Silicon Valley Laoshan Tunnel Project.

4.3. Buried and measurement of monitoring instruments in the partition wall
The anti-cracking performance of the Laoshan tunnel partition wall is tested by using a portable detector to realize the monitoring of the Laoshan single-arch tunnel. The stake number is K31+735~K36+315, and the two sides are installed symmetrically on the surface of the center partition wall. Eight strain gauges, using the strain gauge for detecting concrete to detect the changing law of the strain inside the concrete, within the first 15 days 1~2 times/d, 16~30 days once/d, the layout of the monitoring points is shown in Figure 9.
4.4. Analysis of calculation results of anti-cracking of glass fiber partition wall

4.4.1. Analysis of test results. Check the crack growth of the glass fiber concrete in the partition wall of the tunnel. After curing for a period of time, the statistical data shows that there is no glass fiber in the concrete in the partition wall. The length of the crack is 14.5 cm. The height of the compression zone generated by it is 4.5 m; the length of the cracks with 0.5% glass fiber added to the concrete in the partition wall is 7.3 cm, 2.1 cm, and 5.6 cm, and the height of the compression zone generated is respectively 3.8 m, 2.8 m, 3.4 m, it is concluded that the cracks in the partition wall with glass fiber added to the concrete are small.

4.4.2. Analysis of calculation results.

Figure 9. Layout of measuring instruments for the middle partition wall.

Figure 10. Comparative analysis of calculation results and test results of the anti-cracking of the partition wall.
The fracture mechanics formula can be calculated: the crack length of the concrete partition wall without glass fiber is 13.9 cm, and the pressure zone height generated by it is 4.3 m; the volume ratio of glass fiber is 0.5%, 1.0%, 1.5% the lengths of the cracks that appeared at the time were 7.1 cm, 2.3 cm, and 5.9 cm, respectively, and the heights of the compression zone produced by them were 3.5 m, 2.1 m, and 3.8 m. In summary, it can be concluded that the test results are consistent with the calculation results as shown in Figure 10.

| Glass fiber ratio (%) | Calculated value of bending moment $M_{cr}$/MPa | Measured value of bending moment $M'_{cr}$/MPa | $M_{cr}/M'_{cr}$ |
|-----------------------|-----------------------------------------------|-----------------------------------------------|------------------|
| 0                     | 176.5                                         | 173.2                                         | 1.02             |
| 0.5                   | 199.3                                         | 201.4                                         | 0.99             |
| 1                     | 216.3                                         | 204.8                                         | 1.07             |
| 1.5                   | 189.6                                         | 186.7                                         | 1.02             |

Through the above analysis of the anti-cracking results of the glass fiber reinforced concrete and ordinary concrete partition walls, combined with Figure 10 and Table 3, it can be seen that the compression zone of the former partition wall is lower than the latter. The calculation results show that the former and the rear The values of the two are about 0.25–0.31, 0.47, the former is 0.53–0.65 times of the latter, it can be concluded that the concrete partition wall with glass fiber has better crack resistance than without glass fiber, and the size of the crack It is also relatively short. When the volume ratio of the glass fiber added to the concrete is 1%, the cracks in the middle partition wall are shorter and the height of the compression zone is lower than other the volume ratio is added.

5. Conclusions
This article mainly relies on the Qingdao Blue Silicon Valley Laoshan Tunnel Project. First, it studies the reinforcement mechanism of glass fiber, analyzes the properties of glass fiber concrete under different parameters, to effectively prevent concrete crack length to determine the optimal length and volume rate, and the application of the glass fiber to the partition wall of the Laoshan Tunnel, at the same time, good technical and economic benefits have been achieved in engineering applications. The specific conclusions are as follows:

(1) The compressive and tensile properties of glass fiber concrete are studied by a combination of theoretical analysis and laboratory experiments, and it is determined that the glass fiber with the best volume rate of 1% and the best length of 12mm can make the concrete slab crack resistant, Higher.

(2) Applying glass fiber concrete to the partition wall of the tunnel, the monitoring data are consistent with the laboratory test data by monitoring the cracking situation and the height of the compression zone, and then it is concluded that the glass fiber partition wall can increase the crack prevention performance of the concrete slab and reduce the number of cracks to a minimum.

(3) By monitoring the cracks of the glass fiber concrete partition wall under different parameters, the results of the optimal length and the optimal volume rate of the indoor test are verified, and the construction quality of the partition wall is guaranteed.

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