Influence of basalt fiber on mechanical properties of permeable cement stabilized macadam base

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Abstract. Different groups of permeable cement stabilized macadam specimens material test, which used different basalt fiber content were carried out, studying the influence of basalt fiber content on compressive strength and splitting strength of materials. The results showed that basalt fiber can improve the long term compressive strength and splitting strength of permeable cement stabilized macadam. When the basalt fiber content is 0.7 ‰ and the fiber length is 12 cm, the compressive strength and splitting strength of the specimen are improved best.

1. Introduction
With the rapid development of cities in China, the problem of urban waterlogging is becoming more and more serious. The sponge cities permeable pavement, which absorb, store, seep and purify water, can effectively solve this problem. Urban roads are designed as permeable pavement with permeable surface and permeable base, which can quickly absorb surface runoff into urban rainwater circulation system, and has important significance for improve urban waterlogging and sponge city construction.

As a kind of permeable pavement base material, permeable cement stabilized macadam has been studied by scholars at home and abroad on its mix proportion, gradation, permeability and other basic properties. Ji Qing-ke [1] et al. studied the composition design method, gradation and cement dosage of permeable cement stabilized macadam mixture; Vavrik R [2] et al. studied the gradation of permeable cement stabilized macadam base; Qin Xin [3] et al. studied the water purification characteristics of permeable cement stabilized permeable base combining with sponge city. However, the mechanical properties of basalt fiber are seldom studied. The paper carried out a series of material performance tests on permeable cement stabilized macadam. On this basis, the parameters of basalt fiber content and fiber length were optimized, which has guidance for the application of permeable cement stabilized macadam material.

2. Permeable cement stabilized macadam base
Permeable cement stabilized macadam is a kind of porous and stable material, which is composed of certain graded crushed stone, cement and other admixtures in a certain proportion [4] (as shown in Figure 1). It is widely used based on good water permeability, anti-deformation ability and certain strength [5].
2.1. Material properties
The main functions of permeable cement stabilized macadam include [6]: (1) As the bearing layer of pavement structure, it bears the vertical force of traffic load transmitted by pavement surface, and diffuses and distributes it to cushion and soil foundation; (2) It can effectively reduce the surface runoff and improve the driving safety in rainy days; (3) Permeable cement stabilized macadam permeable layer also has the function of temporary water storage, which can store the water that is too late to discharge or penetrate into the soil foundation; (4) As a new type of environmental protection permeable pavement, the base course can also play the role of absorbing road noise, decomposing automobile exhaust gas and filtering and purifying the permeated water. Therefore, the most important function of permeable cement stabilized macadam is bearing, water permeability and water absorption, and has certain stability, strength and durability to meet the traffic load [7].

2.2. Mechanical property
As a permeable base, permeable cement stabilized macadam should have a certain strength and stiffness, in order to better bear the wheel load transferred by the surface layer and spread it to the subgrade. Therefore, this paper mainly analyzes its compressive strength and splitting strength [8].

2.2.1. Test methods for compressive strength. Permeable cement stabilized macadam belongs to the category of inorganic binder stabilized materials. Therefore, the determination method of its compressive strength refers to Test Methods of Materials Stabilized with Inorganic Binders for Highway Engineering (JTGE51-2009) [9]. The compressive strength is calculated according to formula (1):

\[ R_c = \frac{P}{A} \]  

Where \( R_c \) is the unconfined compressive strength of the specimen, in MPa; \( P \) is the maximum pressure at failure, in N; \( A \) is the cross-sectional area of the specimen, in \( \text{mm}^2 \).

2.2.2. Test methods for splitting strength. Permeable cement stabilized macadam belongs to the category of inorganic binder stabilized materials. The determination method of its splitting strength
refers to Test Methods of Materials Stabilized with Inorganic Binders for Highway Engineering (JTGE51-2009) [9]. The splitting strength is calculated according to formula (2):

$$R_i = \frac{2P}{\pi dh} \left( \sin 2\alpha - \frac{a}{d} \right)$$  \hspace{1cm} (2)

Where $R_i$ is the splitting strength of the specimen, in MPa; $d$ is the diameter of the specimen, in mm; $a$ is the width of the bead, in mm; $\alpha$ is the center angle of the circle corresponding to the width of the half pressing strip, in °; $P$ is the maximum pressure when the specimen fails, in N; $h$ is the height of the immersed specimen, in mm

### 3. Influence of basalt fiber on mechanical properties of permeable cement stabilized macadam

#### 3.1. Basalt fiber

Basalt fiber is a popular additive for modified concrete and asphalt mixture in recent years. It has the following advantages: (1) It has excellent physical and mechanical properties, which tensile strength of basalt fiber is generally between 3000MPa and 4800 MPa; (2) It also has good chemical stability. Basalt fiber has strong acid-base resistance and good waterproof; (3) Besides, compared with other additives, basalt fiber has higher cost performance.

The permeable cement stabilized macadam is a framework pore structure with high porosity. The basalt fiber is too long, which is easy to block in the space of permeable cement stabilized macadam, which will affect its strength and permeability. Therefore, combined with the existing basalt fiber length in the market and the characteristics of permeable cement stabilized macadam mixture, the basalt fiber length is 6 mm, 12 mm and 18 mm. In the test, the content of basalt fiber refers to the mass ratio of basalt fiber to gravel in basalt fiber cement stabilized macadam. The proposed content of basalt fiber is 0.3 ‰, 0.5 ‰, 0.7 ‰, 0.9 ‰. The physical and mechanical properties of basalt fiber (as shown in Figure 2) added in permeable cement stabilized macadam base are shown in Table 1.

![Figure 2. Basalt fiber.](image)

| Length (mm) | Unit (μm) | Density (kg/m³) | Elastic modulus (GPa) | Tensile strength (GPa) | Fracture extensibility (%) |
|-------------|-----------|-----------------|-----------------------|-----------------------|---------------------------|
| 6, 12, 18   | 15        | 2650            | 80-100                | 3.3-4.5               | 2.5-3.0                   |
3.2. Experimental study

In this experiment, the orthogonal test is adopted (as shown in Figure 3 and Figure 4). The basalt fiber length is 6 mm, 12 mm, 18 mm, and the fiber content is 0.3 ‰, 0.5 ‰, 0.7 ‰, 0.9 ‰.

![Figure 3. Compressive strength test.](image)

![Figure 4. Splitting strength test.](image)
3.2.1. Test methods for compressive strength. In order to determine the effect of fiber length and content on the compressive strength of permeable cement stabilized macadam, the mixture with different basalt fiber length and different content was designed to test the 14 day compressive strength. The test results are shown in Table 2 and Figure 5.

Table 2. 14d compressive strength of basalt fiber permeable cement stabilized macadam

| Additive | Length | 0mm  | 6mm  | 12mm | 18mm |
|----------|--------|------|------|------|------|
| 0.0‰    | 7.31   | —    | —    | —    | —    |
| 0.3‰    | —      | 7.42 | 7.58 | 7.44 |
| 0.5‰    | —      | 7.63 | 7.83 | 7.69 |
| 0.7‰    | —      | 7.73 | 7.94 | 7.81 |
| 0.9‰    | —      | 7.63 | 7.81 | 7.76 |

Figure 5. Compressive strength

It can be seen from Figure 5 that the 14d compressive strength of permeable cement stabilized macadam is higher after adding basalt fiber. Different basalt fiber length and content have different effects on the compressive strength of permeable cement stabilized macadam. From the addition amount of basalt fiber, when the content of basalt fiber of different length is 0.7 ‰, the improvement effect of compressive strength is the most obvious. From the basalt fiber length, 12mm length has the most significant effect on improving the compressive strength of permeable cement stabilized macadam.

3.2.2. Test methods for splitting strength. The results of splitting strength test are shown in Table 3 and Figure 6.

Table 3. Performance parameters of basalt fiber

| Basalt fiber content | 7day splitting strength /Mpa | 14day splitting strength /Mpa | 28day splitting strength /Mpa |
|---------------------|-------------------------------|-------------------------------|-------------------------------|
| 0.0                 | 6.51                          | 7.31                          | 7.66                          |
| 0.3                 | 5.83                          | 7.58                          | 8.21                          |
| 0.5                 | 5.92                          | 7.83                          | 8.59                          |
| 0.7                 | 5.95                          | 7.94                          | 8.76                          |
| 0.9                 | 5.90                          | 7.81                          | 8.63                          |
Figure 6 shows the change of splitting strength with age of permeable cement stabilized macadam with different amount of basalt fiber. It can be seen from the curve in the figure that the splitting strength of the mixture has a great relationship with the curing age of the specimen. With the increase of the age, the splitting strength of the specimens with and without basalt fiber is increasing. When the content of basalt fiber is 0.7 ‰, the splitting strength of permeable cement stabilized macadam is improved most obviously. The main reason is that too much fiber is not easy to disperse evenly in the mixture.

4. Conclusion
When basalt fiber is added, the later compressive strength and splitting strength of permeable cement stabilized macadam are improved. Through the analysis of the strength of permeable cement stabilized macadam with different length and amount of basalt fiber, the results show that when the length of basalt fiber is 12mm and the content is 0.7 ‰, the compressive strength and splitting strength of the permeable cement stabilized macadam are the best. The 28d compressive strength can be increased by 14.4%, and the 28d splitting strength of the specimen is increased by 8.5%.

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