

# INFLUENCE ON PAVEMENT PERFORMANCE OF POROUS CEMENT STABILIZED MACADAM BY ADDING POLYPROPYLENE FIBER

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**Abstract.** For designing and improving performance of porous cement stabilized macadam, design method for porous cement stabilized macadam was proposed based on Bailey method and Taibal Method. Influence on mechanical properties by different porosity and adding Polypropylene fiber were analyzed through experiment. Results show that design method for porous cement stabilized macadam, based on Bailey method and Taibal Method, could be used for designing of porous cement stabilized macadam. With porosity increasing, unconfined compressive strength and splitting strength were decreasing, and influence was significant. Adding Polypropylene fiber had little influence on porosity, but could improve unconfined compressive strength and splitting strength significantly, influence on unconfined compressive strength and splitting strength by fiber content (volume fraction) were greater, while influence by fiber length were greater on splitting strength. 1.5% was proper fiber content and 18mm was proper fiber length.

## 1. INTRODUCTION

Porous cement stabilized macadam base layer is one of the solutions to eliminate rainwater seepage from the road surface. As a water-permeable material, the porous cement stabilized macadam has the function of “storing and seepage”, and can also be applied to “sponge road” and “sponge city” construction. Therefore, the design and research of porous cement stabilized macadam has attracted the attention of engineers. At present, the design of porous cement stabilized macadam is mainly based on guiding provisions or trial experience in the *Drainage Design Code for Highways* (CAO Yu-ling, 2010; ZHANG Chao, 2014; XIE Jun, et al., 2005; HU Li-qun, et al., 2006), the addition of fiber to improve the performance of porous cement stabilized aggregate has also been rarely reported. In order to solve the design of porous cement stabilized macadam and improve the strength performance of porous cement stabilized macadam, this paper proposes a design method for porous cement stabilized macadam, based on the Bailey method and the Taibal method (PENG Bo, et al., 2005; GUO Yin-chuan, et al., 2014; Zhang Ai-qin, 2000). The method is used to design the porous cement stabilized macadam, and experimental studies are conducted to analyze the effect of the polypropylene fiber added on the performance of the porous cement stabilized macadam.



## 2. POROUS CEMENT STABILIZED MACADAM DESIGN

According to the Bailey method, the porous cement stabilized crushed stone is divided into coarse aggregate and fine aggregate. The coarse aggregate forms the skeleton and the fine aggregate fills it. Coarse aggregate forms skeleton gaps VCA to (PENG Bo, et al., 2005; GUO Yin-chuan, et al., 2014):

$$VCA = (1 - \rho_d / \rho_b) \times 100\% \quad (\text{Eq. 1})$$

Where:  $\rho_d$  = design density of coarse aggregate,  $\rho_b$  = bulk density of coarse aggregate.

The gravel used in this study comes from the Beijing-Shanghai high-speed expansion project, originating in Tongling, all parameters meet the specification requirements. The aggregate has a maximum particle size of 31.5 mm and a nominal particle size (NMPS) of 26.5 mm. According to the Bailey method, the boundary sieve of the coarse aggregate and the fine aggregate is 0.22NMPS and is 4.75 mm. According to the Taibal method, the pass rate of each sieve is calculated as follows (Zhang Aiqin, 2000):

$$p = 100 \times \left(\frac{d}{D}\right)^m \quad (\text{Eq. 2})$$

Where:  $D$  = maximum particle size of aggregates,  $d$  = sieve size,  $m$  = gradation index.

According to the aggregate used in the design, according to the Taibal calculation, the mixture grades are shown in Table 1. According to the screening quality of sieves at all levels, the blending of blends is controlled:

Table.1 Gradation of coarse aggregate and fine aggregate

	Coarse aggregate							Fine aggregate	
Size of screen mesh (mm)	31.5	26.5	19	16	13.2	9.5	4.75	2.36	1.18
pass rate (%)	100	91.7	77.7	71.3	64.7	54.9	38.8	27.4	19.4

According to the gradation of coarse aggregates in Table 1, coarse aggregates were mixed, and the measured bulk density of the coarse aggregate was 2.753 g/cm<sup>3</sup>. The vibration was used for molding. The measured density of the coarse aggregate was 1.887 g/cm<sup>3</sup>. The material skeleton gap is 31.5%.

Since the coarse aggregate forms a skeleton, when the volume of the mixture is  $V$ , the coarse aggregate amount  $m_c$  is:

$$m_c = \rho_d \cdot V \quad (\text{Eq. 3})$$

Cement hydration requires the combination of 25% of its own mass of water to form long-lasting substances, the volume of which absorbs 75% of the volume of free water (Czernin, W., 1991). The ratio of cement to take  $\gamma_{ce}$ , cement mass  $m_{ce}$  and cement volume  $V_{ce}$ :

$$m_{ce} = (\rho_d \cdot V + m_f) \cdot \gamma_{ce} \quad (\text{Eq. 4})$$

Where:  $m_f$  = mass of fine aggregate,  $\gamma_{ce}$  = mass ratio of cement.

$$V_{ce} = 0.25 \times 0.75 \times \frac{(\rho_d \cdot V + m_f) \cdot \gamma_{ce}}{\rho_w} \quad (\text{Eq. 5})$$

Where:  $\rho_w$  = design density of water.

Set the target porosity  $n$  as needed,  $V_{ce}$  can be obtained from Eq. 6:

$$V_{ce} = V \cdot (VCA - n) - 0.25 \times 0.75 \times \frac{(\rho_d \cdot V + m_f) \cdot \gamma_{ce}}{\rho_w} \quad (\text{Eq. 6})$$

According to Eq. 6, the fine aggregate content is:

$$m_f = \frac{V \cdot (\text{VCA} - n) - \frac{3}{16} \times \frac{\rho_d \cdot V \cdot \gamma_{ce}}{\rho_w}}{\frac{1}{\rho_d} + \frac{3}{16} \times \frac{\gamma_{ce}}{\rho_w}} \quad (\text{Eq. 7})$$

In the test, a standard sample has a diameter of 15cm and a height of 15cm. According to the Eq.3, the coarse aggregate of one sample is about 5kg. Due to the design of a porous cement-stabilized gravel, the recommended cement design for *Highway Cement Concrete Pavement Design (JTG D40-2011)* is 9.5%-11%. In this paper, the cement content  $\rho_c$  is taken as 10%. In the test, to achieve the maximum porosity, the fine aggregate content is 0, and the theoretical porosity of the mixture according to Eq.6 is 27.9%; the gradation design is completely carried out according to the Taibo method, and the porosity is minimum at this time. The porosity was 4.5%, the mass ratio of coarse aggregate to fine aggregate was 3.14, and the theoretical porosity was set to 20%. At this time, the mass ratio of coarse aggregate to fine aggregate was 9.27.

### 3. TEST PLAN

The test aggregate comes from the Beijing-Shanghai high-speed expansion project, originating in Tongling, and cement uses 32.5 Ordinary Portland Cement. The coarse aggregate, fine aggregate, and cement in the test were determined according to the above design method. The pore-type cement stabilized gravel mix was designed according to the theoretical porosity of 27.9%, 20%, and 4.5%, and was recorded as I, II, and III. In order to analyze the effect of fiber-doping on the properties of the blends, polypropylene fibers were used in the tests. The parameters of the polypropylene fibers are shown in Table 2 and the mix design was completed at a theoretical porosity of 27.9%. In the experiment, the effects of fiber length and fiber content (volume content) on the properties of the mixture were analyzed. The length of the fiber was selected according to the supply conditions on the market. The levels of 6mm, 12mm and 18mm were selected; the fiber content was normal stable. The research results of the stone include three levels 1‰, 1.5‰, and 2‰ (Kang Ai-hong, et al., 2012; ZHANG Peng, et al., 2008; HE Xiao-bing, 2010). The specific test scheme is shown in Table 3. Because the fiber content is small (1‰~2‰), fiber volume is not counted.

Table.2 Technical parameters of polypropylene fiber

Density (g/cm <sup>3</sup> )	Acid and alkali resistance	Melting point (°C)	Tensile strength (MPa)	Elastic modulus (GPa)	Diameter (μm)	Fracture elongation
0.95	good	165	358	3.5	33	>15%

Table.3 Experiment scheme

Influencing Factors	Mixture number	Theory porosity (%)	Fiber content (‰)	Fiber length (mm)
Mixture without fiber	I	27.9	0	0
	II	20	0	0
	III	4.5	0	0
Influence by fiber content	IV	27.9	1	
	V	27.9	1.5	18
	VI	27.9	2	
Influence by fiber length	VII	27.9		6
	VIII	27.9	1.5	12
	V	27.9		18

The test piece is formed by vibration. According to the main performance requirements of the semi-rigid material and the need to exert the function of water permeability, water storage and drainage, the

test index adopts effective porosity (connected porosity), unconfined compressive strength, and splitting strength. The porosity determination method is referred to the Second reference, and the rest of the test methods mainly refer to *Test Procedures for Inorganic Binder Materials for Highway Engineering (JTG E51-2009)*.

#### 4. TEST RESULTS AND ANALYSIS

The test sample was used to determine the effective porosity, 7d unconfined compressive strength and 28d splitting strength. The results are shown in Table 4.

Table.4 Experiment results

Mixture number	Effective porosity (%)	Unconfined compressive strength (MPa)	Splitting strength (MPa)
I	19.7	2.062	0.357
II	11.3	6.359	1.082
III	3.1	8.552	1.151
IV	16.2	3.935	0.871
V	16.9	4.174	0.932
VI	16.4	4.219	0.968
VII	16.2	4.118	0.711
VIII	17.3	4.121	0.873

From the experimental results, it can be seen that using this method to design a fiber-free mixture (I, II, III), the effective porosity is positively correlated with the theoretical porosity. The ratio of effective porosity to theoretical porosity is 66.3%, 56.5%, and 68.9%, respectively. The main reason is that as the theoretical porosity decreases, the fine aggregate in the mixture increases, and the connected pores follow decrease. With the theoretical porosity as a design index, the requirements for effective porosity of the porous cement stabilized macadam can be met.

For the fiber-stabilized porous cement-stabilized gravel (IV~VIII), the ratios of effective porosity to theoretical porosity were 54.5%, 56.9%, 55.2%, 54.5%, and 58.2%, respectively, and the ratio was generally lower than that of unmixed fiber. This means that as the fiber is added, the interconnected porosity of the mixture decreases. From the results, it can be seen that the fiber length and fiber content have no significant effect on the effective porosity. This is because the fiber content is relatively small (1‰ to 2‰). Under this condition of fiber content, the design method of the porous cement stabilized macadam mixture is also applicable.

As the effective porosity increases, the unconfined compressive strength and splitting strength decrease. The effective porosity increased from 3.1% to 19.7%, the unconfined compressive strength decreased by 75.9%, and the splitting strength decreased by 69.0%. It can be seen that the compressive strength and tensile strength are closely related to the porosity, the porosity is large, the content of fine aggregate is small, the contact area between the aggregates is small, the stability of the cement is restricted, and the strength is reduced. The effective porosity increased from 3.1% to 11.3%, the effective porosity increased by 264.5%, the unconfined compressive strength decreased by 25.6%, the splitting strength decreased by 6.0%, and the effective porosity increased from 11.3% to 19.7%. The porosity increased by 74.3%, the unconfined compressive strength decreased by 67.6%, and the splitting strength decreased by 67.0%. It can be seen that the strength of the porous cement stabilized macadam increases with the increase of the specific gravity of the fine aggregate, but as the fine aggregate increases, the influence of the fine aggregate on the strength also gradually weakens.

With the addition of polypropylene fibers, the unconfined compressive strength and splitting strength of the mix have been effectively improved. In the test, the fiber-doped samples exhibited obvious plastic failure characteristics, and the unconfined compressive strength specimens still maintained good integrity without significant cracking. When the splitting strength test piece is broken, the two sides of the crack are connected by fibers and still have a certain tensile strength.

The fiber content increased from 0 to 1‰, the unconfined compressive strength increased by 90.8%, and the splitting strength increased by 144.0%. The fiber content increased from 1‰ to 1.5‰, the unconfined compressive strength increased by 6.1%, and the splitting strength increased by 8.2%. The fiber content increased from 1.5‰ to 2‰, the unconfined compressive strength increased by 1.1%, and the splitting strength increased by 2.8%. This is due to the addition of fibers, which enhances the integrity of the mix. Randomly dispersed fibers have high tensile strength, have a certain restraining effect on the skeleton, and can share part of the load. When the fiber content exceeds 1.5‰, the effect of increasing fiber content on strength is no longer significant.

When the fiber length increased from 6mm to 12mm, the unconfined compressive strength increased by 0.1% and the splitting strength increased by 22.8%. When the fiber length increased from 12mm to 18mm, the unconfined compressive strength increased by 1.3% and the splitting strength increased by 6.8%. It can be seen from the results that the fiber length has less influence on the unconfined compressive strength and the impact on the splitting strength is relatively large. The reason is that the splitting strength is more dependent on the tensile strength that the fiber can exert. The tensile strength exerted by the fiber depends on the connection between the fiber and the mineral and the tensile strength of the fiber itself. Due to the high tensile strength of the polypropylene fiber, the connection force between the fiber and the mineral material becomes a factor restricting the tensile strength of the fiber. The longer the fiber length, the greater the connection force between the fiber and the mineral material. As the length increases further, from 12mm to 18mm, under the same amount of content, the number of fibers is reduced, so the impact on the strength of the mixture is small.

## 5. CONCLUSION

(1) Whether it is fiber-free cement stabilized gravel or fiber cement stabilized gravel, there is a clear positive correlation between theoretical porosity and effective porosity. The addition of 1‰ to 2‰ of fiber has no significant effect on the porosity of the mix. The design method of the porous cement stabilized macadam with the theoretical porosity index can be used for the design of common porous cement stabilized macadam and the design of fiber-filled porous cement stabilized macadam.

(2) The unconfined compressive strength and splitting strength of non-fiber cement stabilized macadam are greatly affected by the porosity. With the theoretical porosity, unconfined compressive strength and splitting strength decreased significantly. The practical application needs to combine the requirements of load, horizon, seepage, and water storage to set a reasonable porosity.

(3) Adding polypropylene fiber can significantly improve the unconfined compressive strength and splitting strength of the porous cement stabilized aggregates. With the increase of fiber content, its effect on strength gradually weakened. According to this experiment, the fiber content is recommended to take 1.5‰.

(4) Under the condition of the same fiber content, the fiber length has little influence on the unconfined compressive strength of the porous cement-stabilized macadam, and has a great influence on the splitting strength. The longer the fiber length, the greater the splitting strength. Under the condition of the same amount of fiber, the longer the fiber, the smaller the number of fiber, which has an adverse effect on the tensile strength of the fiber. According to the test conditions, it is feasible to take the fiber length to 18mm.

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