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Effect of Polypropylene Fiber on Shrinkage Properties of Cement-stabilized Macadam

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Abstract

A parametric experimental study has been conducted to investigate the effect of polypropylene fiber on the shrinkage of cement-stabilized macadam. By means of the micrometer gauge method and the strain gauge method, the dry shrinkage coefficient and thermal shrinkage coefficient of cement-stabilized macadam were measured respectively. The results indicate that polypropylene fiber can effectively decrease the average dry shrinkage coefficient and average thermal shrinkage coefficient of cement-stabilized macadam. The average dry shrinkage coefficient of long curing period is smaller than that of short curing period, while the average thermal shrinkage coefficient of long curing period is much larger than that of shot curing period. When the fiber volume fraction is not beyond 0.1%, the average dry shrinkage coefficient and average thermal shrinkage coefficient are gradually decreasing with the increase in fiber volume fraction. Furthermore, polypropylene fiber appears to be highly effective in controlling dry and thermal shrinkage cracking of cement-stabilized macadam.

Keywords: Cement-stabilized macadam, Polypropylene fiber, Dry shrinkage, Thermal shrinkage, Average shrinkage coefficient

1. Introduction

As a kind of material of semi-rigid base course in asphalt pavements, compared with other semi-rigid base course materials, cement-stabilized macadam is characterized by its advantages, such as higher strength and rigidity and more excellent wholeness and water stability. Therefore, it has been used as the main base course material of high-grade highways with semi-rigid base courses and asphalt surface layers for a long period in China. However, this material also presents some disadvantages such as high brittleness, poor resistance to deformation and high shrinkage rate, so it is prone to crack when it is subjected to the changes of temperature and humidity.

Some research has indicated that polypropylene fiber can improve the resistance to deformation and anti-cracking property of cement-stabilized macadam effectively, while the strength of cement-stabilized macadam will decrease a little after mixing with polypropylene fiber. Accordingly, polypropylene fiber has better application prospect in cement-stabilized macadam to control shrinkage cracks. However, the above-mentioned polypropylene fibers applied in cement-stabilized macadam are all long fibers, the length of which is from 50 to 70 mm. Currently only a limited number of documents are found on the properties of cement-stabilized macadam reinforced with polypropylene short fiber. However, none of the other phases have been studied the dry and thermal shrinkage properties of cement-stabilized macadam reinforced with polypropylene fiber. Therefore, we conducted this parametric study to investigate the effects of polypropylene short fiber on the mechanical properties and shrinkage properties of cement-stabilized macadam. In this study, the length of the polypropylene short fiber is from 10 to 20mm. The properties of dry shrinkage and thermal shrinkage are evaluated with the indices of average dry shrinkage coefficient and average thermal shrinkage coefficient respectively.

2. Materials and Experimental Methods

2.1 Materials used

The polypropylene fiber used in this investigation was bunchy single short fiber, which was manufactured by mixing modified polypropylene short fiber with different lengths and section shapes together in proportion in special production techniques. The basic physical properties of polypropylene fiber in this study are shown in Table 1. Four fiber volume fractions were adopted (0.04, 0.06, 0.08 and 0.1%). The cement used was the Class 42.5R Ordinary Portland cement with the content of 5%. The macadam used was composed of five kinds of aggregates with different size ranges. The aggregate has a maximum size of 30mm, and the aggregate with a minimum size of 2.5mm was replaced by river sands. The fineness modulus of the river sands is 2.73. The composite gradation of the aggregate referred to the median of the gradation range prescribed for cement-stabilized base course materials of high-grade highway in the Chinese standard (JTJ 014-97, 2001). The gradation of the macadam adopted in this investigation is shown in Table 2.

2.2 Preparation of specimens

A series of beam specimens with the size of 100×100×400 mm were used to determine the average dry and thermal shrinkage coefficients. The beam moulds for the preparation of beam specimens were self-made steel moulds, which were designed referring to the preparing principle of cylinder specimens in the Chinese Standard (JTJ 057-94, 2004). All the specimens were prepared by compacting at their respective maximum dry density and optimum moisture content, and the compacting and stripping of the specimens were both carried out by pressure testing machine. Before being stripped, the specimens were covered by plastic sheets and allowed to stand for 4-5 h. After stripping, the specimens sealed in plastic sheets were cured at 100% relative humidity and controlled temperature (21 ± 2 ^{o}C) before testing. In order to compare the effect of polypropylene fiber, besides the four sets of specimens of polypropylene fiber cement-stabilized macadam, another set of specimens without mixed fibers was prepared.

2.3 Dry shrinkage test

Dry shrinkage test was carried out in the constant temperature box with the constant temperature of 40 ^{o}C. The specimen was supported by several glass bars with the same diameter on a pallet fixed in a bracket, and two micrometers with dial indicators were fixed in the bracket to measure the dry shrinkage deformation. After the testing began, the additional specimen was weighed every 2 h until the last two weights were equal. Finally, the final numerical reading shown in the micrometer with dial indicator was noted. The dry shrinkage coefficient can be computed as follows:

$$\alpha_d = \frac{\varepsilon}{\omega_2 - \omega_1} \tag{1}$$

$$\varepsilon = \frac{\Delta_2 - \Delta_1}{L} \tag{2}$$

where, α_d, dry shrinkage coefficient, με/%; ε, dry shrinkage strain, με; Δ_1, Δ_2, initial and final numerical reading shown in the micrometer with dial indicator respectively, mm; ω_1, ω_2, initial and final moisture contents of the specimen respectively, %; L, length of the specimen, mm. For dry shrinkage tests, each set includes 3 specimens, and the average value of 3 data was computed as the final result.

2.4 Thermal shrinkage test

Thermal shrinkage test was carried out in the Hi-Lo temperature experimental box with the temperature range of 40 to -20 ^{o}C. The thermal strain was measured by resistance strain gauges (Hu, 2004). The initial temperature of the experimental box was set to be 40 ^{o}C, and the initial strain was read after the temperature was kept unchanged for 4 h. Then the temperature was lowered from 40 to -20 ^{o}C at the rate of 0.5 ^{o}C /min, and the final strain was read after the temperature of -20 ^{o}C was kept unchanged for 4 h. The thermal shrinkage coefficient can be computed as follows:

$$\alpha_t = \frac{\varepsilon_2 - \varepsilon_1}{T_2 - T_1} + \beta \tag{3}$$

where, α_t, thermal shrinkage coefficient, με/ ^{o}C; ε_1, ε_2, initial and final thermal strain respectively, με; T_1, T_2, initial and final temperature in the experimental box respectively, ^{o}C; β, thermal shrinkage coefficient of the temperature compensation plate, με/ ^{o}C. For thermal shrinkage tests, each set also includes 3 specimens, and the average value of 3 data was computed as the final result.

3. Experimental Results and Discussion

3.1 Effect of polypropylene fiber volume fraction on dry shrinkage property

Fig. 1 shows the varying rule of the average dry shrinkage coefficient of non-fibrous cement-stabilized macadam and polypropylene fiber-reinforced cement-stabilized macadam as the volume fraction of fiber varies. From the figure, it can be seen that polypropylene fiber can effectively restrain the dry shrinkage of cement-stabilized macadam. For instance, when the volume fraction of polypropylene fiber is 0.1%, compared with non-fibrous cement-stabilized macadam, the average dry shrinkage coefficient (28d) decrease 42%. After polypropylene fibers were mixed into cement-stabilized macadam, as the binding material of the sands and macadam, cement also bonds a large number of fine and short fibers. So the area of water loss of the cement-stabilized macadam will be reduced, and the water inside the matrix is difficult to move, which will decrease the capillary tension produced by the shrinkage for water loss of capillaries. Meanwhile, there are interface cohesive strength and mechanical interlocking action between the matrix and the fiber. Therefore, the average dry shrinkage coefficient was evidently decreased after polypropylene fibers were mixed into cement-stabilized macadam. When the curing period is 7d, the comprehensive action of the capillary tension, the intermolecular force of the adsorbed water and the shrinkage force of the interlayer water inside cement-stabilized macadam is much smaller than that of 28d, and therefore the average dry shrinkage coefficient of 7d is higher than that of 28d (Zhang, 2006). However, whether the curing period is 7d or whether the curing period is 28d, there is a tendency of decrease in the average dry shrinkage coefficient of cement-stabilized macadam with the increase of polypropylene fiber volume fraction within the range of the fiber dosage in this study, which is not beyond 0.1%. As the volume fraction of polypropylene fiber increases, the number of randomly distributed fibers in cement-stabilized macadam mixture increases. According to the fiber spacing theory (Nemkumar, 2006, pp. 1263-1267), the confinement force of fibers on the mixture and cement paste will increase if the spacing between two adjacent fibers decreases, so the restriction of fibers on dry shrinkage of the mixture is strengthened. As a result, the average dry shrinkage coefficient will have a tendency of decrease as the volume fraction of polypropylene fiber increases.

3.2 Effect of polypropylene fiber volume fraction on thermal shrinkage property

Fig. 2 shows the contrast relationship between the average thermal shrinkage coefficient of non-fibrous cement-stabilized and polypropylene fiber-reinforced cement-stabilized macadam with different fiber dosages. From the figure, it can be seen that the addition of polypropylene fiber can decrease the average thermal shrinkage coefficient effectively. For instance, when the volume fraction of polypropylene fiber is 0.1%, the average thermal shrinkage coefficient (28d) decreases from 8.0 $\mu\varepsilon/^{o}C$ (non-fibrous cement-stabilized macadam) to 6.3 $\mu\varepsilon/^{o}C$, and it is reduced by 21%. The cement-stabilized macadam reinforced with polypropylene fiber can be regarded as a kind of composite material, and its thermal properties depend upon the comprehensive action of the matrix and the fibers. The thermal coefficient of polypropylene fiber is very small, which is only about 10% of that of cement-stabilized macadam, and therefore when the composite material is subjected to drops in temperature, it is not sensitive to the temperature variation. Moreover, the polypropylene fibers distributed in cement-stabilized macadam are in three-dimensional and disordered directions, and they will form a network structure by overlapping each other. Therefore, polypropylene fiber can obviously decrease the average thermal coefficient of cement-stabilized macadam. At the early stage of the curing period, the ratio of various binding materials and hydrates with higher thermal coefficient in the whole composite material is much smaller, and the ratio will increase with the running of various chemical reactions inside the mixture. As a result, the average thermal shrinkage coefficient of polypropylene fiber-reinforced cement-stabilized macadam of 28d is higher than that of 14d. However, when the fiber dosage is not beyond 0.1%, whether the curing period is 14d or whether the curing period is 28d, the inhibit function of the fibers on the thermal shrinkage of cement-stabilized macadam is strengthened with the increase of polypropylene fiber volume fraction, and accordingly, the average thermal shrinkage coefficient of cement-stabilized macadam is decreasing gradually.

4. Summary and Conclusions

This paper reported experimental results of dry and thermal shrinkage studies conducted on cement-stabilized macadam reinforced with polypropylene fiber. The following conclusions can be draw from the results presented in this paper:

1) Polypropylene fiber is highly effective in controlling the dry and thermal shrinkage of cement-stabilized macadam. A 0.1% dosage of fibers (by volume fraction) resulted in a 42% decrease in the dry shrinkage coefficient and a 21% decrease in the thermal shrinkage coefficient of cement-stabilized macadam (28d). The decrease in the dry and thermal shrinkage coefficients will improve the anti-cracking performance of cement-stabilized macadam base course obviously.

2) With the increase of polypropylene fiber volume fraction, and accordingly, there is a tendency of decrease not only in the average dry shrinkage coefficient but also in the average thermal shrinkage coefficient of cement-stabilized macadam, and consequently, the crack resistance of cement-stabilized macadam base course will be increased gradually.

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Table 1. Physical properties of polypropylene fiber

Density (g/cm^3)	Linear density (dtex)	Fiber length (mm)	Tensile strength (MPa)	Elastic modulus (MPa)	Melting point (°C)
0.91	10~20	10-20	≥ 450	≥ 4100	160~170

Table 2. Gradation of the macadam

Sieve size (mm)	31.5	19	9.5	4.75	2.36	0.6	0.075
Percentage passing of aggregate (%)	100	94.3	67.64	41.96	26.9	9.68	0.26

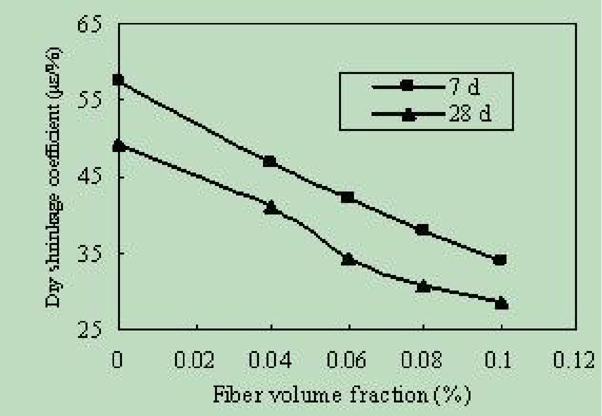

Figure 1. Effect of fiber volume fraction on dry shrinkage coefficient

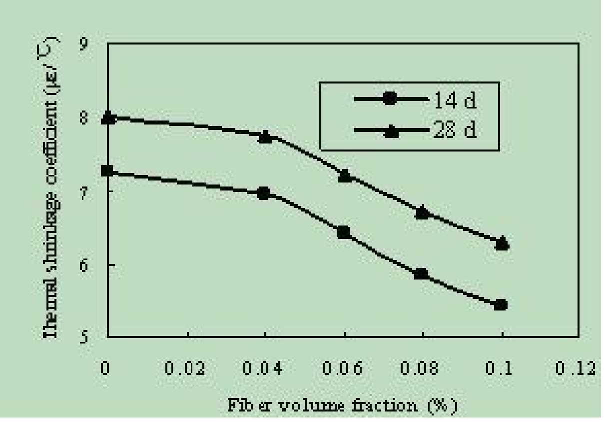

Figure 2. Effect of fiber volume fraction on thermal shrinkage coefficient