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The bending fatigue performance of cement-stabilized aggregate reinforced with polypropylene filament fiber

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HIGHLIGHTS

- The fatigue performances of CAPFF with low fiber content are studied.
- The bending fatigue equations of five different materials are established.
- CAPFF has higher fatigue life/strength than ordinary cement-stabilized aggregate.
- The fatigue resistance of CMPFF is more superior than that of CGPFF.
- SEM is adopted to analyze the enhancement of fiber to anti-fatigue ability.

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ABSTRACT

Cement-stabilized aggregate reinforced with polypropylene filament fiber (CAPFF) is a new material for road base course of semi-rigid pavements whose bending fatigue performance has been rarely studied. The paper studied the bending fatigue performances of CAPFF (including two types of CAPFF, i.e., cement-stabilized macadam and gravel respectively reinforced with polypropylene filament fiber) with low mixing content, and then established their bending fatigue equations. Results show that, when under the same stress level, the fatigue life of CAPFF is improved by 1.0–4.2 times comparing with that of ordinary cement-stabilized aggregate. Meanwhile, the analysis of the fatigue equations indicates that, when using fibers, the bending fatigue strength of mixtures is appreciably improved, respectively about 30% in case of CMPFF and about 20% for CGPFF. When the stress level is under 0.75, the enhancement of fiber to cement-stabilized macadam is better than to cement-stabilized gravel; when the stress level is higher than 0.75, a reverse conclusion can be obtained. Ultimately, by the results from microtopography analysis by scanning electron microscope (SEM), the enhancement of the polypropylene filament fiber to the bending fatigue resistance of the cement-stabilized aggregates is analyzed.

1. Introduction

Semi-rigid base is one of the main basic base forms in asphalt pavement structure in highway, and the semi-rigid base materials represented by cement-stabilized aggregates are widely used in road construction in various countries. However, the semi-rigid base made of cement-stabilized aggregates has some disadvantages which are hard to overcome, such as large dry shrinkage coefficient and temperature shrinkage coefficient, large brittleness, poor adaption to the deformation and poor crack resistance. Those disadvantages are unfavorable to the road performance of the asphalt pavement and its service [1–3]. In a long time, various methods have been proposed in researches to overcome the above disadvantages of semi-rigid base made of cement-stabilized aggregates [4–11].

In the existing researches on the anti-crack technologies of semi-rigid base, cement–bitumen treated materials (CBTM) and cement-stabilized aggregate reinforced with polypropylene filament fiber (CAPFF) are considered to be the two excellent materials in anti-cracking ability. Researches on CBTM have been conducted

Abbreviations: CAPFF, cement-stabilized aggregate reinforced with polypropylene filament fiber; CMPFF, cement-stabilized macadam reinforced with polypropylene filament fiber; CGPFF, cement-stabilized gravel reinforced with polypropylene filament fiber.

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since 1970s [12], which has yielded lots of research findings and been widely applied. However, CAPFF, as a new material which was studied recently, has been rarely used in engineering. By means of mixing polypropylene filament fiber into cement-stabilized aggregate, the coefficients of dry shrinkage and temperature shrinkage of the material can be significantly reduced, and toughness and crack resistance can be enhanced [13–18].

When with the same cement dosage, the performance of CAPFF varies with the parameters (length, content and diameter) of fiber, while the performance of CBTM differs a lot with the parameters (properties and content) of emulsified bitumen. Comparing with those of ordinary cement-stabilized materials, the contraction coefficient, elastic modulus of the CAPFF and CBTM are decreased, while the toughness, ultimate deformation capacity and anti-cracking capacity are improved. Xiao Peng et al. [6] have studied the enhancement effects of SBR-modified bituminous emulsion (the ratio between its mass and the mass of cement is 5–15%) and polypropylene fiber (the volume content is between 0.06% and 0.1%) respectively on cement-stabilized macadam with a certain cement dosage. Their results show that both SBR-modified bituminous emulsion and polypropylene fiber can remarkably decrease the elastic modulus and improve the contraction and anti-cracking capacity, and the enhancement effect of polypropylene fiber is better. In fact, when the emulsified bitumen is of high mixing content, the elastic modulus of CBTM will decrease more obviously. In the aspect of strength, the usage of polypropylene fiber has little influence on the strength of cement-stabilized materials, while generally the usage of bituminous emulsion will substantially decrease the strength of the materials. In the aspect of thermal dependency, that of CBTM is higher, and the indirect tensile strength and elastic modulus of CBTM will significantly increase as temperature decreases. However, the strength and elastic modulus of CAPFF are barely influenced by temperature. In the aspect of fatigue performance, there are few researches on CAPFF while much more on CBTM, thus no comparison between their fatigue performances can be carried out. Bullen [19] indicate according to their practice in South Africa that the fatigue performance of C-ETM is poor and tends to crack in an early age. Schmidt et al. [20] and Nakamory et al. [21] indicate according to indoor experiments and test road verification that the fatigue performance of CBTM is poor. Only when the mass ratio of cement is within 3%, the possibility of fatigue cracking can be reduced. Moreover, in the aspects of economy, resource dependence and resource consumption, the economy of CBTM is not as good as that of CAPFF, which highly depends on bitumen resources, while CAPFF consumes more cement. Grilli et al. [22], and Bocci et al. [23,24] based on the technology of cold-in-place recycling (CIR) of asphalt pavement, have conduct a research on the performance and application of CBTM, which has led to rich findings and has great significance for a resource-saving and environmental friendly construction and development mode on the basis of solving the economic issues of CBTM.

The existing researches on CAPFF mostly focused on its dry shrinkage, temperature shrinkage and static performance. However, some other important properties of the road base, i.e., fatigue properties, have been rarely investigated. From the perspective of fracture mechanics, the bending failure process of CAPFF is a process of emergence and development of cracks. According to the superposition principle of stress intensity factor in linear elastic fracture mechanics, when the crack develops across fiber, the anchoring force produced by fiber and mixture will provide a reverse stress intensity factor at the crack tip, preventing further extension of the crack [18]. Basing on the fatigue crack growth rate given by the famous Paris law [25], the mixing of polypropylene filament fiber will reduce the growth rate of fatigue cracks in the cement-stabilized aggregate as to enhance the anti-fatigue performance of the material. The enhancement of polypropylene filament fiber to the bending fatigue performance of the cement-stabilized aggregate is closely related to the anchoring force between the fiber and the cement-stabilized aggregate. The bigger the anchoring force is, the greater the enhancement is.

Some China scholars such as H.H. Yang et al. [26] have studied the fatigue performance of cement-stabilized aggregate reinforced with polypropylene fiber, in which the polypropylene fiber was plastic bag fiber instead of the synthetic polypropylene filament fiber widely used in road engineering. They have not discussed the influence of fiber content and length on the fatigue performance. The fiber used in their research is of high mixing content, the mass percent of which is 5%, and their mixture was made of only cement-stabilized macadam without using and studying another commonly used cement-stabilized aggregate i.e., cement-stabilized gravel.

Aiming at the insufficiencies of existing research, this paper selected two most representative cement-stabilized aggregates, namely, cement-stabilized macadam and cement-stabilized gravel, as the research objects of the paper, and studied the fatigue performances of the cement-stabilized aggregates with different dimensions of polypropylene filament fiber with low content. Furthermore, the fatigue equation and bending fatigue strength have been obtained and the results have been compared with those of ordinary cement-stabilized aggregates. Finally, based on the results from SEM, the anti-fatigue performance of the polypropylene filament fiber to cement-stabilized aggregates is analyzed.

2. Experimental program

2.1. Materials

2.1.1. Cement

Portland cement P.O 32.5 was employed in the research, and its main technical indexes are shown in Table 1.

2.1.2. Polypropylene filament fiber

Physical and mechanical parameters of the chosen polypropylene filament fiber are shown in Table 2.

2.1.3. Aggregates

Two kinds of cement-stabilized aggregate, i.e., cement-stabilized gravel and cement-stabilized macadam, were selected for the experiment. CAPFF was formed by mixing polypropylene filament fiber with ordinary cement-stabilized aggregate, including cement-stabilized gravel reinforced with polypropylene filament fiber (CGPFF) and cement-stabilized macadam reinforced with polypropylene filament fiber (CMPFF). The gradation curves of aggregate for CGPFF and CMPFF are shown in Fig. 1.

According to the specifications of China (JTG E42-2005), the crushed value and plastic index were tested. The test on the crushed value of an aggregate is as follows. First, loading on the aggregate to a certain load value within a certain time. Then the weight ratio of the crushed aggregate under a certain diameter is recorded as the crushed value. Test results show that the crushed value of the aggregate in CGPFF is 9.9%, and its plastic index is 7.5%; and the crushed value of the aggregate in CMPFF is 11.5%, and its plastic index is 3.7%.

Table 1
The major technical indexes of cement (JTG E30-2005, Chinese standard).

Items	Fineness (%) (the 80 μm sieve)	Setting time (min)		3 day strength (MPa)		Soundness
		Initial setting	Final setting	Compressive	Flexural	
Value	2.4	202	345	18.5	3.68	Qualified