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Influence of mineral nano-fibers on the physical properties of road cement concrete material

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HIGHLIGHTS

- Waste brucite short fibers processed to nano diameter level with a simple way.
- The physical properties of brucite nano-fiber reinforced concrete have been improved.
- Nano-fiber concrete superior to ordinary concrete in cost performance.
- 8 years traffic practice proves the practicability of nano-fiber concrete.

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ABSTRACT

In this paper, brucite nano-fiber is processed and used as reinforcement to improve the toughness of road cement concrete material. The brucite nano-fiber is obtained by soaking the natural low-coat brucite short fibers in the superplasticizer solution and then agitating in a forced mixer to refine it to the nano meter level. The mechanical properties as elastic modulus, dry shrinkage, anti-frost, thermal expansion, and flexural fatigue performance of the nano-fiber concrete are investigated. The nano-fiber reinforced cement concrete was also put into practice in highway. Results show that nano-fiber concrete has better toughness. Its flexural strength is 7.4% and 17.7% higher than that of the ordinary fiber concrete and the plain concrete, respectively. Its ratio of compression to flexural strengths is 6.4% and 16.1% lower than that of the rest two. Nano-fiber concrete has lower static modulus and higher dynamic modulus. Compared with ordinary fiber concrete and plain concrete, nano-fiber concrete is 41.0% and 61.3% lower in flexural elastic modulus, and is 1.12 and 1.24 times higher in dynamic modulus of elasticity. Nano-fiber concrete has stronger capability to resist dry shrinkage, freeze-thaw damage, thermal expansion and bending fatigue stresses. Compared with ordinary fiber concrete and plain concrete, nano-fiber concrete is 35.7% and 55.9% lower in dry linear shrinkage; 3.2% and 7.9% less loss rate in compression strength, and 1.9% and 4.5% less loss rate in flexural strength after 50 cycles freezing-thawing; 13.9% and 28.7% lower in coefficient of thermal expansion; and 15% and 50% more longer in bending fatigue service life. Nano-fiber concrete is comprehensively superior to ordinary fiber concrete and plain concrete in cost performance. After more than 8 years traffic practice, the nano-fiber concrete test road is still in good condition.

1. Introduction

Cement concrete pavement has good qualities of high strength and stiffness, strong water-resistance and stable high-temperature property, and exhibits obvious advantage in the heavy load and weak roadbed areas [1,2]. However, cement concrete is a brittle material due to its feature of heterogeneous, multiple defects, low tensile strength, and low deformation capacity, it is ease to fracture under tension, bending and impact load, which leads to a premature failure [3,4]. It is significant to strengthen the tensile strength and toughness of cement concrete for prolonging its service life.

In general, the effective approach to enhance the anti-bending performance of the road concrete is to employ fibers as the reinforcement to strengthen it [5,6]. Brucite fiber, or fibrous brucite (FB), is a kind of natural mineral fiber rich in China. It is mainly composed of $Mg(OH)_2$ and has strong alkali resistance, good compatibility and strong binding force with cement concrete. It is also harmless to the human health [7,8].

The aim of this paper is trying to use a simple way to process the low-cost ordinary brucite fibers into nano-diameter fibers,

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and then using them as reinforcements in the road concrete to improve the properties of the cement concrete.

2. Experimental

2.1. Raw materials and properties

2.1.1. Mineral fibers

Grade 7-X brucite fibers [9] from Shaanxi province were used. They are short fibers from the dust collector and mill tailings in the mine. The optical photo is shown in Fig. 1. The fiber parameters are shown in Table 1.

The fibers are usually used as fillers simply instead of reinforcing phase due to their very short length.

2.1.2. Superplasticizer

Based on the results of our previous work [9–11], compound admixture of different chemicals was used as the superplasticizer in the test, so as to both improve the properties of concrete and split brucite fiber bundles as well as disperse fibers in concrete.

The superplasticizer admixture is prepared by mixing the materials with the mass ratio of naphthalene water reducer: aliphatic water reducer: Amino sulfonate reducer: sodium gluconate: methanol: water = 1: 1.5: 3: 0.05: 0.15: 2. The measured solid content of the result admixture is 29%, and its performance index meets the requirement of quality standards of *Concrete Admixture*(-GB8076-2008).

2.1.3. Coarse aggregate

The coarse aggregate is the 4.75–26.5 mm fabricated continuous grading limestone gravel, which is prepared by the mass proportion of gravel 1$^{\#}$(size 26.5 mm-19 mm): gravel 2$^{\#}$ (size 19–9.5 mm): gravel 3$^{\#}$(size 9.5–4.75 mm) =0.5: 0.4: 0.1. The screen analyst result is shown in Fig. 2 and meets the 4.75–26.5 mm nominal diameter of the *Technical Specification for Construction of Highway Cement Concrete Pavements(JTG F30-2003).*

Fig. 1. Brucite fibers.

Table 1
Parameters of brucite fibers.

Aspect ratio		Specific surface area, cm^2/g	Sieve analysis, wt%		
Range	Average		+1.4 mm	+0.4 mm	Sieve bottom
14–143	53	239	12	35	53

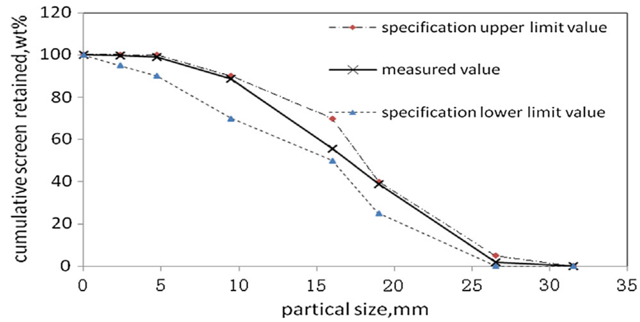

Fig. 2. Screen analysis result of the coarse aggregate.

2.1.4. Other raw materials

Other raw materials include P.O.42.5$^{\#}$ Portland cement, fineness modulus 2.9 river sand and water. They all meet the *Technical Specification for Construction of Highway Cement Concrete Pavements (JTG F30-2003).*

2.2. Processes of mineral nano-fibers

The brucite fibers were processed as follows: mixed the brucite fiber, superplasticizer and water at the mass ratio of 1: 0.96: 0.54 homogeneously, and stood for 24 h in order that the fibers could be soaked by the superplasticizer solution, then mechanically agitated inside a forced mixer for 10 min, aging the paste for 0.5 h, then collected and packed up the fiber paste for future use.

Fig. 3 shows the comparative SEM(Scanning Electron Microscope) photos of fibers before and after processing. Fig. 3-A shows the original fibers, while Fig. 3-B presents the processed ones. The original fibers are in the state of closely combined fiber bundles with the diameters of about 1.5–46.3 μm. The diameters of processed fibers are about 45–110 nm, mostly are around 60 nm. The aspect ratio becomes march larger than the original fibers.

Fig. 3 reveals that the original micro-diameter fibers become nano-diameter fibers after processed by the simple way of soaking with superplasticizer solution and agitating in forced mixers.

To understand the mechanism of the naturally produced ordinary brucite fiber changing to the nano-fibers, further tests were conducted.

Fig. 4-A and B show SEM photos of the enlarged original brucite fiber and the fibers soaked by superplasticizer solution for 24 h. Table 2 is the surface Zeta Potentials of original and processed brucite fibers in deionized water measured with JS94G + type electrophoresis apparatus under condition of 25Δ°C, 1.4A, 30 V, PH7 and voltage switching period 1000 ms.

Fig. 4-A indicates that brucite fiber, as a natural fibrous mineral, is produced in the forms of closely bonded bundles. In fact, a single macro fiber is actually composed of much more finer fibers. It is an aggregation of many thinner fibers. After soaked in superplaticizer solution, the brucite fiber bundles are loosened (Fig. 4-B). Under the action of mechanical force of the mixer, the loosened fiber bundles are split into single fine fibers (Fig. 3-B).

From Table2, it shows that the surface of the original brucite fibers brings positive charges, while the processed brucite fiber presents negative charges. This phenomenon should be related with the chemical adsorption of surfactant [12,13].

We all know that, water reducers are indispensable chemical agents in the modern concrete industry. They play some important parts in the concrete, such as, reducing the water content, enhancing the workability, improving the mechanical properties, etc. Since different water reducers have different functions, usually admixtures of water reducers were used for a better performance of the concrete. While in this paper, water reducers have the additional function of splitting the fiber bundles, as shown in Fig. 5.