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Study on the Properties of Graphene Fiber Concrete Materials for Energy Piles

Zechen Liu, Lincong Zhou

Jilin University, Changchun 130021, Jilin, China

Abstract: ***Energy piles are employed as innovative buried pipe structures within ground source heat pump systems, leveraging the superior specific heat capacity and heat transfer characteristics of concrete materials. Research was conducted on graphene concrete energy piles, wherein graphene fiber concrete was formulated by incorporating various quantities of graphene into steel fiber concrete. The findings indicate that, in comparison to conventional fiber concrete, graphene fiber concrete exhibits minimal alterations in flexural and split tensile strengths, a notable enhancement in compressive strength, and a considerable boost in thermal conductivity. These advancements demonstrate that the enhanced graphene concrete positively impacts the lifespan extension and long-term stable functionality of energy piles in challenging environmental conditions.***

Keywords: Energy stake, Graphene Fiber concrete, Mechanical property, Thermal conductivity.

1. Introduction

Concrete material is a kind of cost-effective material widely used in the engineering field with high practicality, low cost and high strength [1]. With the continuous development of China's construction projects, the requirements for various properties of concrete are also increasing. In recent years there have been more and more researches on concrete modification materials, and the modification requirements for the mechanical properties of concrete with different admixtures are also increasing [4-5]. Research in recent years has found that the incorporation of steel fibers in concrete can effectively improve the mechanical properties of concrete [2-3]. Li Wei [6] and Yang Yong [7] studied the mechanical properties of steel fiber concrete, and the results showed that the admixture of steel fibers effectively improved the compressive strength, splitting tensile strength and flexural strength of concrete. Zhang Xuemei [8] et al. studied the mechanical properties and frost resistance of graphene-modified concrete, which showed that graphene can enhance the compressive strength and frost resistance of concrete with an optimum admixture of 0.08%. Liu Kai, Wang Fang, Wang Xuancang et al [11] studied the influence of aggregate volume fraction, sand rate, water-cement ratio, temperature, fiber type and admixture on the thermal conductivity of concrete, fiber type and admixture play a dominant role in the thermal conductivity of concrete, aggregate volume fraction, temperature and water-cement ratio of the influence of the second, the sand rate of the influence of the smallest. The prototype of energy piles was proposed in the 1980s. In order to optimize the overall heat exchange efficiency of the energy pile system, Zhao Songying [9] et al. proposed to improve the thermal conductivity of the pile concrete as as a direction of improvement. Kong [10] et al. mixed graphene into the concrete and found that it could enhance the heat exchange performance of the whole pile group. On the basis of the previous work, this paper attempts to incorporate graphene in steel fiber concrete to explore and study its mechanical properties.

2. Experimental Materials and Methods

2.1 Experimental Materials

The cement selected for this experiment was composite silicate cement with strength class 42.5. The fine aggregate is natural river sand with a fineness modulus of 2.4. Its density was determined as 2.65×103kg/m^3, and its water content was 5%. Coarse aggregate is gravel with uniform particle size gradation and maximum particle size of 20mm. For graphene, graphene powder was selected, as shown in Figure 1 below. The selected steel fiber is shear type steel fiber, and its parameters and pictures are shown in Table 2 and Figure 2 below. Other materials are water reducers and blast furnace slag and tap water.

Figure 1: Graphene powder

Figure 2: Sheared steel fiber

Table 1: Steel fiber parameters

Name	Lengths [mm]	Diameter [mm]	L/D ratio	Tensile Strength [Mpa]
Shear Steel Fiber	10-15	0.3-0.5	20-50	>600

2.2 Experimental Methods

Due to the hydrophobicity and poor dispersibility of graphene, it is necessary to modify the pretreatment of graphene during the test, and a simpler way of treatment was chosen in the actual experiments, i.e., a pre-prepared graphene oxide dispersion with a concentration of 2 mg/mL was used. The technical parameters of the graphene dispersion used are shown in Table 2.

Trial blocks were made based on C40 strength concrete. The trial mixing work of graphene steel fiber concrete was carried out according to the steel fiber content of 1%, water reducing agent content of 1% and blast furnace slag content of 4% through the calculation of the mix ratio and absolute volume method. The mass fractions of graphene to cementitious materials were set as two parts per million, four parts per million and six parts per million, respectively, and the calculated mix ratios of graphene steel fiber concrete are shown in Table 3.

Table 2: Technical parameters of graphene dispersion

Color	Thickness [μm]	Single-layer Sheet Diameter [μm]	Strippability [%]	Carbon Content [%]	Oxygen Content [%]	Sulfur Content [%]	Ash Content [%]	Vibration Density [g/L]	Granularity
Tan	1	0.2-10	95	12.7	51.6	2.1	1.0	500	80

Table 3: Material consumption of 1 m3 panel graphene concrete [unit: kg].

Number	Steel Fiber	Water Reducing Agent	Blast Furnace Slag	Fine Aggregate	Coarse Aggregate	Cementitious Material	Water	Graphene
1	27.40	1.63	13.07	614.25	607.06	430.00	185.00	0.000
2	27.40	1.63	13.07	614.25	607.06	430.00	185.00	0.086
3	27.40	1.63	13.07	614.25	607.06	430.00	185.00	0.172
4	27.40	1.63	13.07	614.25	607.06	430.00	185.00	0.258

The specimens were prepared according to the mixing ratio in Table 3, and the mechanical and thermal conductivity tests were carried out after the specimens reached the maintenance standard. For compressive strength test, WHY-2000 microcomputer-controlled pressure tester was selected, for flexural resistance, universal testing machine was selected, and for split tensile test, concrete press was selected. Thermal conductivity is tested by SSX-DX300 thermal conductivity tester.

3. Data Analysis

3.1 Test Results of Compressive Strength of Graphene Steel Fiber Concrete

Compared with the control concrete specimens without graphene addition, the graphene concrete specimens with different dosages showed a certain degree of strengthening effect in terms of strength, and their compressive strengths were 62.22 Mpa, 61.94 Mpa, and 64.29 Mpa, which were increased by 5.4%, 4.92%, and 8.91%, respectively. These results confirm that graphene can enhance the compressive strength of concrete materials, and this strengthening effect is reflected under different conditions of graphene dosage. The variation curve of compressive strength of specimens with graphene dosage is shown in Figure 3.

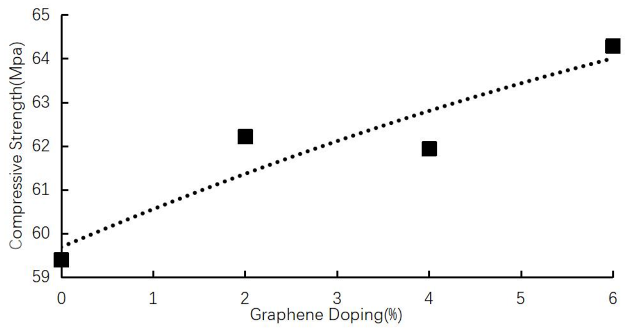

Figure 3: Compressive strength curve of graphene doping

The test results were fitted and analyzed to obtain formula 1.

$$f'_{cu} = f_{cu} - 0.0726x^2 + 1.2586x \quad (1)$$

Correlation Coefficient: R^2=0.8638.

In the formula: f'_{cu}—Graphene fiber concrete compressive strength [MPa]; f_{cu}—Compressive strength of steel fiber concrete [Mpa]; x—10000 times graphene volume doping $(0 \le x \le 7)$. **Flexural Strength Test Results of Graphene Steel Fiber Concrete**

Compared with the control concrete specimens without graphene, the concrete specimens after graphene mixing did not show significant enhancement in the index of flexural strength, which were 4.74 Mpa, 4.65 Mpa, and 4.44 Mpa, respectively, which indicated that under the conditions of this test, graphene's effect on improving the flexural properties of concrete specimens was not obvious, and the variation of specimen flexural strength with graphene mixing was not significant, as shown in Figure 4. curve is shown in Figure 4.

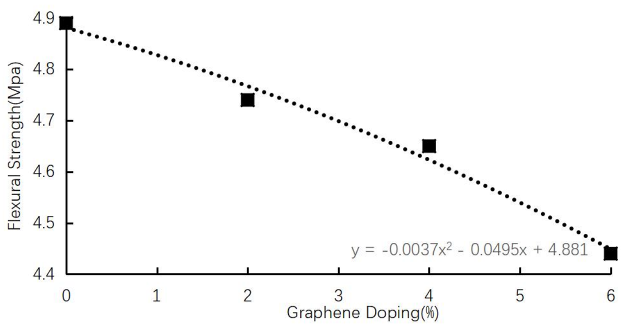

Figure 4: Graphene doping flexural strength curve

The test results were fitted and analyzed to obtain formula 2.

$$R'_b = R_b - 0.0032x^2 - 0.0545x \quad (2)$$

Correlation Coefficient: R^2=0.9836.

In the formula:R'_b—Graphene fiber concrete flexural strength

[Mpa]; R_b—Flexural strength of steel fiber concrete [Mpa]; x—10000 times graphene volume doping$(0 \le x \le 7)$.

3.2 Test Results of Split Tensile Strength of Graphene Steel Fiber Concrete

The splitting tensile strengths of graphene-fiber concrete were 5.90 MPa, 5.83 MPa, and 6.12 MPa, respectively, and compared with the concrete specimens without graphene doping, the splitting tensile strengths did not show a significant decrease, but instead, generally showed a weak enhancement trend. Therefore, it can be concluded that in a specific mixing range, increasing the graphene content can slightly improve the splitting tensile properties of concrete, and the variation curve of splitting tensile strength of specimens with graphene mixing is shown in Figure 5.

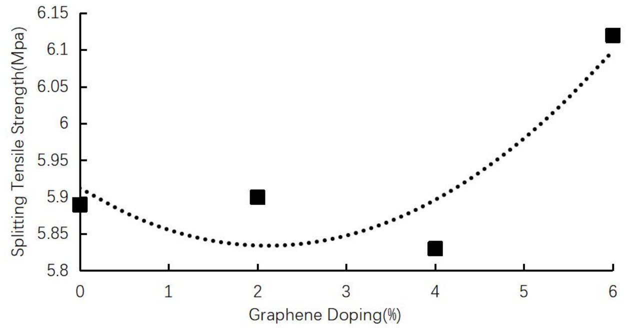

Figure 5: Graphene doping splitting tensile strength curve

The test results were fitted and analyzed to obtain formula 3.

$$f'_{ct} = f_{ct} + 0.0313x^2 - 0.079x \quad (3)$$

Correlation Coefficient: R^2=0.6472.

In the formula: f'_{ct}—Graphene steel fiber concrete splitting tensile strength [MPa]; f_{ct}—Splitting tensile strength of steel fiber concrete [Mpa]; x—10000 times graphene volume doping$(0 \le x \le 7)$.

3.4 Thermal Conductivity Test of Graphene Fiber Concrete

Concrete specimens mixed with graphene showed variable variations in thermal conductivity, both increasing and decreasing. For the samples with decreasing thermal conductivity, the possible reasons are due to the surface treatment of the concrete specimens is not flat enough or there is inhomogeneity in the preparation process, which leads to the deviation of the thermal conductivity measurement results. The variation curve of thermal conductivity of specimens with graphene doping is shown in Figure 6.

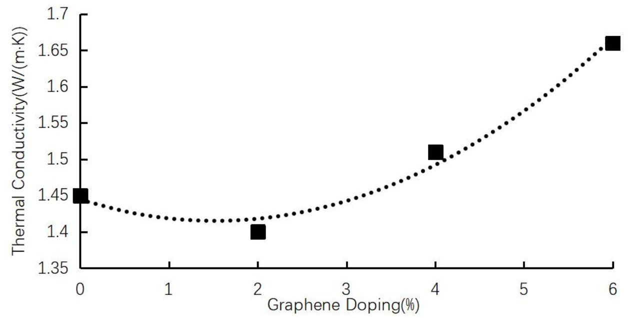

Figure 6: Graphene doping thermal conductivity curve

The test results were fitted and analyzed to obtain formula 4.

$$\lambda' = \lambda + 0.0129x^2 - 0.0413x \quad (4)$$

Correlation Coefficient: R^2=0.9801.

In the formula: λ'—Thermal conductivity of graphene fiber concrete (W/(m·K)); λ—Thermal conductivity of steel fiber concrete (W/(m·K)); x—10000 times graphene volume doping$(0 \le x \le 7)$.

4. Conclusion

The compressive, flexural and splitting tensile strength determination tests were conducted with a change in graphene content. The effect of different graphene content on the compressive, tensile and flexural properties of steel fiber concrete was investigated.

The following conclusions were drawn from the analysis of the test results:

1) graphene steel fiber concrete has a significant improvement in compressive properties compared to ordinary steel fiber concrete. The compressive strength was increased by 5.4%, 4.92% and 8.91% respectively.

2) The changes in flexural strength and split tensile strength of graphene steel fiber concrete were not significant, indicating that the role of graphene in improving the two mechanical properties of concrete is relatively limited, i.e., the effect of graphene on the flexural and split tensile properties of concrete is relatively small.

3) In terms of thermal conductivity of graphene-mixed concrete specimens, when the amount of graphene is 4/10,000 and 6/10,000, the coefficient of thermal conductivity is improved by 4.1% and 14.5% compared with the control group.

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