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Study of mechanical properties and thermal conductivity of energy storage phase change concrete with activated carbon

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The results of a study of the thermal conductivity and mechanical properties of phase change concrete with various fillers are presented. It has been shown that with the addition of an energy saving aggregate with activated carbon, the compressive and splitting strength of concrete decreases. The addition of silica powder can improve the compressive strength and splitting strength of concrete. When the content of the energy storage aggregate with activated carbon is 15% and the content of silica powder is 10%, the compressive and tensile strength of concrete increases. When the phase change material is in the liquid state, the thermal conductivity of the phase change concrete is greater than that in the solid state, and the increase range is less than 6%. With increasing content of energy storage aggregate with activated carbon, the thermal conductivity of phase change concrete increases significantly.
Keywords: Phase change concrete; Energy storage aggregate with activated carbon; Compressive strength; Splitting tensile strength; Thermal conductivity

Дослідження механічних властивостей та теплопровідності бетону з фазовим переходом, що акумулює енергію з активованим вугіллям. *Hai Cao, Yankun Ma*

Наведено результати дослідження теплопровідності та механічних властивостей бетону з фазовим переходом із різними наповнювачами. Показано, що з додаванням агрегату для енергозбереження з активованим вугіллям міцність на стиснення та розколювання бетону зменшується. Додавання порошку кремнезему може покращити міцність на стиск та міцність на розколювання бетону. Коли вміст агрегату для збереження енергії з активованим вугіллям становить 15%, а вміст кремнеземного порошку - 10%, міцність бетону на стиск і розтяг збільшується. Коли матеріал з фазовим переходом знаходиться в рідкому стані, теплопровідність бетону з фазовим переходом більша, ніж у твердому стані, а діапазон збільшення становить менше 6%. Зі збільшенням вмісту енергоакумулятора з активованим вугіллям теплопровідність бетону з фазовим переходом значно збільшується.

1. Introduction

Energy saving of buildings has always been the focus, and phase change energy storage structures are the focus of research at this stage [1-2]. By combining phase change composite materials with building materials, a new type of high-efficiency and energy-saving phase change structures can slow down the temperature fluctuation of buildings, improve the temperature resistance of buildings, effectively improve the durability of buildings, and achieve the purpose of energy storage and temperature control to reduce building energy consumption [3-4].

The application of phase change materials in concrete can improve the thermal and physical properties of concrete, improve the energy storage capacity of buildings, and achieve the effect of building energy saving [5]. Adding phase change energy storage materials to concrete is the main factor affecting the mechanical and thermal properties of concrete [6-8]. The phase change energy storage concrete prepared by Ma Qinyong et al. [9-10] has high compressive strength, but to use it in load-bearing structures, it is necessary to take into account its destructive ability [11]. Wang Jun [12] used limestone powder to modify the surface of phase-change energy storage aggregate and found that limestone powder could make the phase-change energy storage aggregate behave as hydrophilic, thus reducing the strength loss of concrete. However, due to its poor mechanical properties, the phase-change energy-storage concrete cannot be applied to the load-bearing structures of the building [13], and the strength can only be improved by adding admixtures. As a kind of industrial waste, silicon powder is widely used in concrete, which can protect the environment and improve the strength of concrete, consistent with the concept of green building [14].

In this paper, butyl stearate was adsorbed by columnar activated carbon with diameter of 6 mm to obtain an energy storage aggregate with activated carbon. The phase change concrete was prepared by adding it into concrete as part of coarse aggregate. The compressive strength, splitting tensile strength and thermal conductivity of phase change concrete with different carbon storage aggregate and silica powder contents were tested to study the mechanical and thermal conductivity properties of concrete and provide references for engineering practice.

2. Experimental

2.1 Test materials

The phase change energy storage aggregate was prepared by adsorbing the phase change material capric acid-n-caprylic acid with activated carbon as a matrix material, and was used as a coarse aggregate to partially replace stone. The purpose of this paper is to study a kind of high-performance low-temperature phase change energy-storing concrete by adding silica powder as an admixture and a certain amount of water-reducing agent.

Capric acid is a chemically pure reagent produced by Wuxi Prospect Chemical Reagent Co., LTD. N-caprylic acid is a pure analytical reagent produced by Guangdong Wengjiang Chemical Reagent Co., LTD. The phase change material of this test is a capric acid-n-caprylic acid mixed solution, which is colorless and transparent liquid with a mass ratio of 30:70 according to ultrasonic oscillations. The phase transition temperature of the eutectic solution was 4.37 °C and the latent heat of phase transition was 107.6 J/g. The activated carbon is a coal columnar material with 6 mm particle size provided by Pingdingshan Lvzhiyuan Activated Carbon Co., LTD.

Silica powder is produced by Beijing Dechang Weiye Construction Engineering Technology Co., LTD, the content of SiO_2 is 95% and the specific surface area is 15 m^2/g. The water reducing agent is a naphthalene series water reducing agent produced by Shandong Yusuo Chemical Technology Co., LTD.

The cement is P·O42.5R ordinary Portland cement. The fine aggregate is common river sand with fineness modulus of 2.7 from the bank of Xin ‘an River. The coarse aggregate is solid gravel with a particle size of 5 ~ 10mm. Tap water is used for mixing. The concrete strength grade is C30. The compressive strength of the C30 concrete cube is 40.4N/mm^2 and the splitting tensile strength f_t is 3.595N /mm^2. The concrete mix ratio parameters are shown in Table 1.

2.2 Experimental design

The raw activated carbon was put into the pumping filter bottle after water drying and pretreatment, and then the phase change material was poured into the bottle and fully immersed in the activated carbon, and then the rubber plug was inserted, and the pumping pipe was pumped out by a SHZ-D (III) type circulating water vacuum pump. When the pointer reached the negative pressure of 0.1MPa, the vacuum pump was turned off and stood for 10 min, so that the activated carbon could fully

Table1 Mix proportions of concrete

Concrete strength grade	Cement (kg/m3)	Sand (kg/m^3)	Limestone rubble (kg/m^3)	Water (kg/m^3)
C30	436	652	1315	236

Table 2 Compressive strength and splitting tensile strength of phase change concrete

Active carbon energy storage aggregate content /%	Compressive strength /MPa	Loss rate of compressive strength	Splitting tensile strength /MPa	Loss rate of splitting tensile strength
0	39.8	—	3.54	—
5	38.6	3.1%	3.41	3.7%
10	37.5	5.8%	3.32	6.2%
15	36.3	8.8%	3.21	9.3%
20	35.2	11.6%	3.10	12.4%

adsorb the phase change material. The phase change energy storage aggregate with saturated adsorption was taken out by a slotted spoon and spread out to dry and prepare the phase change energy storage aggregate used in the test.

The blending method is used to replace the cement content with 0%, 5%, 10% and 15% silica powder; and phase change energy storage aggregate replaces an equal volume 0%, 5%, 10%, 15% and 20% of sand, according to orthogonal test design mix. Three 150mm × 150mm × 150mm concrete specimens for each component were disassembled 24 hours later and cured for 28 days. The compressive and splitting tensile properties were tested according to the "Standard Test method for Mechanical Properties of ordinary Concrete" (GB/T 50081-2002). The TYE-2000 pressure testing machine was used. The loading rate of compressive test was set to 2 kN/s, the loading rate of splitting tensile strength test was set to 0.2 kN/s, and the test room temperature was about 10 °C. Continuous and uniform load was applied during the loading process.

The thermal conductivity test adopts a XH-PDR 300 thermal conductivity tester produced by Shenyang Xinhe Jingwei Mechanical and Electronic Equipment Co., LTD. The specimen size was 300 mm ×300 mm ×30 mm. After 28 days of standard maintenance, the specimen was dried in a 101-3a type electric blast oven.

Phase change materials have two states, solid and liquid, so the thermal conductivity of phase change concrete is also different in different temperature ranges [15-16]. The melting point of butyl stearate is 18 ~ 20 °C, so two sets of experiments with different hot and cold plate temperatures were carried out. When the cold plate temperature is set to 5 °C and the hot plate temperature is 15 °C, the phase change material is solid. When the temperature of the cold plate is set at 25 °C and the temperature of the hot plate is 35 °C, the phase change material is liquid.

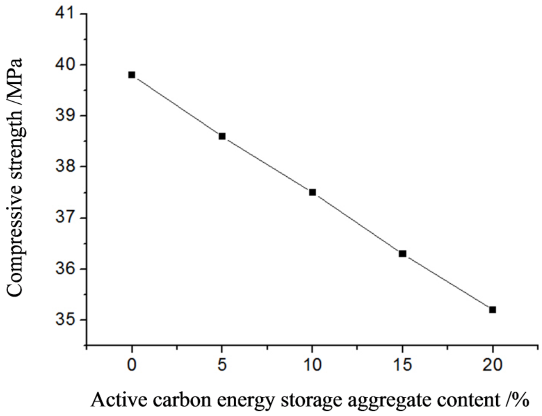

Fig.1 Compressive strength depending on the content of activated carbon energy storage aggregate

3. Results and discussion

3.1 Influence of activated carbon aggregate

The test results show the relationship of compressive strength between single-doped activated carbon aggregate and concrete under standard curing conditions of 28 days (Fig. 1), and the relationship of splitting tensile strength between single-doped activated carbon aggregate and concrete (Fig. 2). The specific test results are shown in Table 2.

According to Table 2, the Fig. 1 and Fig. 2 show the relationship curves between the compressive strength and splitting tensile strength of phase change concrete and the content of activated carbon energy storage aggregate respectively. In order to better analyze the influence of activated carbon storage aggregate content on the compressive strength and splitting tensile strength of phase change concrete, the compressive strength loss rate and splitting tensile loss rate were introduced.

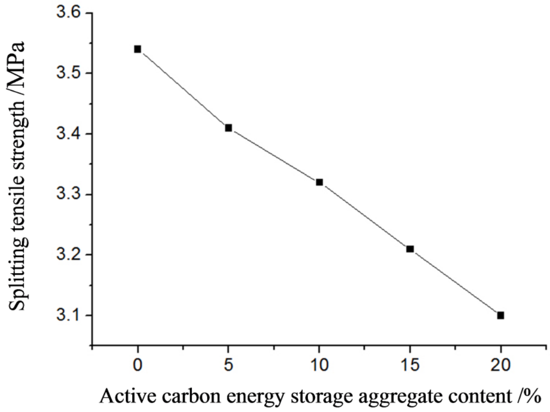

Fig.2 Splitting tensile strength depending on the content of activated carbon energy storage aggregate

It can be seen from Fig. 1 and Fig. 2 that the compressive strength and splitting tensile strength of phase change concrete both decrease with an increase in the content of activated carbon storage aggregate. Since the strength of activated carbon storage aggregate is low, partial replacement of concrete with the aggregate affects the overall strength. At the same time, a layer of butyl stearate is attached to the surface of activated carbon energy storage aggregate, which affects its adhesion to concrete and leads to a decrease in the compressive and tensile strength of phase change concrete.

As can be seen from Table 2, the addition of activated carbon energy storage aggregate increases the strength loss rate of phase change concrete. When the content of activated carbon energy storage aggregate is 5%, 10%, 15% and 20%, the compressive strength loss rate of phase change concrete is 3.1%, 5.8%, 8.8% and 11.6%, respectively. The loss rates of splitting tensile strength were 3.7%, 6.2%, 9.3% and 12.4%, respectively. If the strength loss rate is used as a standard to determine whether the phase change concrete meets the requirements of engineering use, the strength loss rate of phase change concrete should be less than 10%, and the content of activated carbon energy storage aggregate is 15%.

3.2 Influence of double mixing of silica powder and phase change storage aggregate

Addition of phase change energy storage aggregate to concrete leads to the reduction of compressive strength, and addition of silica powder compensates for its reduced strength. Therefore, the addition of phase change energy storage aggregate can be increased as much as possible to improve its heat storage performance without reducing the strength of concrete. Fig. 3 shows the compressive strength of each group of concrete. The splitting tensile strength of each group of concrete is shown in Fig. 4.

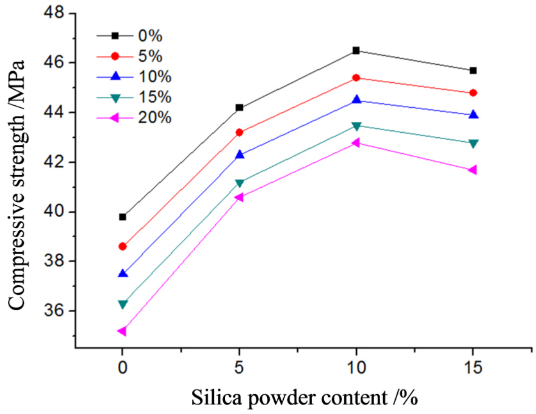

Fig.3. Compressive strength depending on the content of silica powder
(Note: 5% represents the content of activated carbon energy storage aggregate)

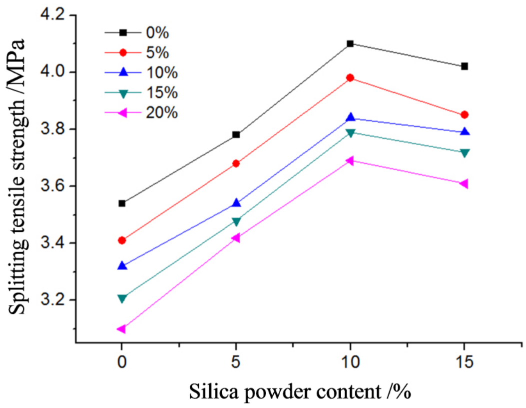

Fig.4 Splitting tensile strength depending on the content of silica powder
(Note: 5% represents the content of activated carbon energy storage aggregate)

The analysis of Fig. 3 and Fig. 4 shows that with an increase in the silica powder content, the compressive strength and splitting tensile strength of concrete both increase, and the compressive strength increases significantly. When the content of activated carbon energy storage aggregate is 15% and the content of silica powder is 10%, the compressive and tensile strength of concrete is 20% and 18% higher than that without silica powder. With an increase in the silica powder content, the silica powder rich in highly active SiO_2 small particles quickly dissolved, and reacted with $Ca(OH)_2$ to form a new substance C-S-H gel, that is, the pozzolanic ef-

Table 3 Thermal conductivity of phase change concrete

Active carbon energy storage aggregate content /%	Thermal conductivity /(W ·m-1 ·K-1)	
	Solid group	Liquid group
0	0.4215	0.4452
5	0.4568	0.4721
10	0.4725	0.4895
15	0.5123	0.5347
20	0.5321	0.5598

fect, thus accelerating the hydration process of cement. The C-S-H gel derived from the reaction of silica powder is mostly generated in the pores during the hydration of cement, thus improving the compactness of cement stone and strengthening the concrete. Therefore, addition of an appropriate amount of silicon powder can effectively improve the strength of phase change concrete with activated carbon energy storage aggregate.

3.3 Tests and analysis of thermal conductivity of phase change concrete

The test results of thermal conductivity of phase change concrete are shown in Table 3.

As can be seen from Table 3, for the phase change concrete with an active carbon energy storage aggregate content of 5%, 10%, 15% and 20%, the thermal conductivity of the liquid group is 3.3%, 3.6%, 4.4% and 5.2% higher than that of the solid group, respectively. It can be seen that the thermal conductivity of the liquid group with a higher set temperature of the hot and cold plate is greater than that of the solid group. When the temperature increases, the molecular movement inside the phase change concrete is intensified, the heat transfer efficiency accelerates, and the thermal conductivity of the phase change concrete increases.

According to the test data in Table 3, the relationship curve between thermal conductivity and activated carbon energy storage aggregate content is drawn, as shown in Figure 5.

It can be seen from Figure 5 that the thermal conductivity of phase change concrete increases with an increase in the content of activated carbon storage aggregate. In the solid state group, the thermal conductivity of phase change concrete with the addition of 5%, 10%, 15% and 20% increased by 8.5%, 12.1%, 21.5% and 26.2%, respectively, compared with that of phase change concrete with 0%. The liquid group increased by 6.0%, 10.0%, 20.1% and 25.7%, respectively.

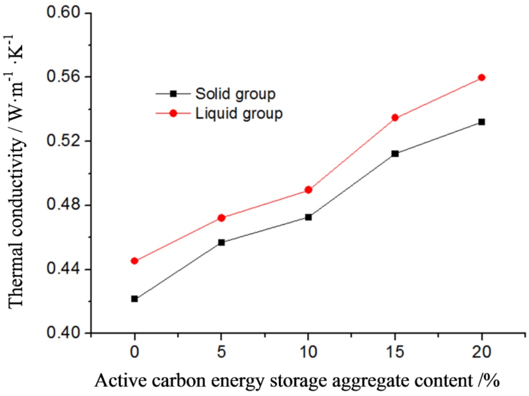

Fig. 5 Thermal conductivity depending on the content of active carbon energy storage aggregate

4. Conclusions

(1) With the addition of activated carbon energy storage aggregate, the compressive and splitting tensile strength of phase change concrete showed a decreasing trend. With the addition of activated carbon energy storage aggregate of 15%, the strength loss rate of phase change concrete was less than 10%.

(2) The addition of silica powder can improve the compressive strength and splitting tensile strength of concrete. When the content of activated carbon energy storage aggregate is 15% and the content of silica powder is 10%, the compressive and tensile strength of concrete is 20% and 18% higher than without silica powder.

(3) When the phase change material is in the liquid state, the thermal conductivity of the phase change concrete is larger than that in the solid state, and the increase range is less than 6%.

(4) With an increase in the content of activated carbon energy storage aggregate, the thermal conductivity of phase change concrete increases significantly to meet the requirements of heat preservation, and the content of activated carbon energy storage aggregate should be less than 15%.

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